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CHINA REPORT
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APPLIED SCIENCES

REGIONAL VIEWS ON SCIENCE, TECHNOLOGY EXPRESSED

Emphasis on Cadre Rotational Training

Xian SHAANXI RIBAO in Chinese 28 Dec 81 p 1

[Text] A vital strategic mission which the party faces is to build by systematic and extensive training a rank of revolutionary, informed, specialized and spirited cadres. It is a prerequisite for the construction of the socialist four modernizations. In 1981, with the emphasis and support of various levels of party committees and governments in Shaanxi and the effort of various party and cadre schools, new progress and prominent achievements were made in the training of cadres in Shaanxi Province. In the meantime, however, many problems still remain. One problem is that progress is not uniform; some regions and cities have trained two-thirds of their cadres whereas others have only trained one-third. The second problem is the large number of no-shows. The most fundamental reason behind this problem is the lack of strategic vision of some of the leading cadres and the effort of cadre training was not given the proper status. The participation in cadre training was often not seriously organized with the excuse of being too busy or not being able to leave the job. Another cause is that some cadres are satisfied with the status quo and believe that they can do their job and last for awhile without further training. There are some cadres who claim this and that difficulty and are unwilling to go to party or cadre schools to learn. Therefore, various party committees must further improve the awareness of cadre training and treat it as a political assignment.

To improve awareness is to understand the new situation after the party's shift in working emphasis. The current thought level, culture standard, and science and technology knowledge of the cadre ranks are still very incompatible with the demands of the socialist modernization construction. Today we have a big job and a long way to go in bringing about socialist modernization. The party and our people are fully confident of and hopeful about China's socialist future. But many of our cadres are not up to the current status. They lack the knowledge of the fundamental theories of Marxism-Leninism and Mao Zedong Thought, they do not understand modern scientific technology and scientific management and many people also lack the self-awareness on these topics. If this kind of situation is not improved, it will inevitably impede the construction of socialist

modernization. Therefore, leading comrades at various levels must fully understand the importance and urgency of accelerated cadre training. All those who have not participated in the training, especially leading cadres at the county level and above, must enter a party or a cadre school within the next 2 years. Each cadre should realize that it is his right and obligation to participate in the training and learning. Without knowledge of Marxist-Leninist theory, and culture, business and science, a cadre is not qualified to do his present job and he will not be able thoroughly to comprehend the party line and policy, not to mention to carry out these policies consciously. Comrade Liu Shaoqi once said: "A cadre not up to standard in Marxist-Leninist theory is a cadre 'not qualified for leadership' and is 'an incompetent cadre.'" Although these words were spoken several decades ago, they remain very significant and informative to those cadres who still do not take the learning of political theory seriously.

The goal of the provincial party committee is to train all the cadres in Shaanxi in 1983. We must improve leadership, pool all initiatives, take practical and effective measures, broaden the learning opportunities, stress quality as well as quantity, and accomplish this assignment on time, so that new improvements can be made in the rank of cadres in Shaanxi Province.

Equipment Renewal, Technological Improvement

Kunming YUNNAN RIBAO in Chinese 11 Dec 81 p 2

[Article by Yu Ming [0060 2494] and Liu Jiabao [0491 0502 0202]: "Yunnan Printing and Dyeing Mill Completes 10 Major Improvement Projects in 1981"]

[Text] Yunnan Printing and Dyeing Mill made a major effort in improving their facility and technology and obtained fast results with only modest investment in production development.

Yunnan Printing and Dyeing Mill is the largest printing and dyeing enterprise in Yunnan Province; it has about 100 sets of large machines, some of which are vintage 1940 and 1950. Because their equipment is old and their technology is outdated, the improvement of quality and quantity is hampered and the sort and variety of their products cannot satisfy the market demand. After an investigation and study, the plant leaders realized that the only way to develop production and to obtain fast results with modest investment is to improve their equipment and technology. Based on the available funds and technical manpower, they chose to upgrade the projects that have the most impact on production. This mill produces 70 million meters of printed and dyed fabrics every year and uses about 50 tons of steam every hour. But the 3 boilers they had could only provide 26 tons of steam per hour. Hence, their boiler shop and repair shop modified the existing boilers into chain boilers and improved the boiler chamber so that steam production per hour was increased to 50 tons to satisfy production needs. After the boiler modification, the labor demand on the workers was reduced and 15 tons of raw coal was saved every day.

While modifying the equipment, they also made an effort to improve the technique. In addition to using a lot of native cloth, the mill also uses large quantities of dye. The type and amount of dye they use have direct effects on the product quality and cost. In order to cut cost without sacrificing quality, the mill adjusted some of their existing formulas in 1981. In the past, for instance, too much shilin [1102 2651] dye was used in producing dark green dacron khaki and resulted in "black shades" on the fabric surface, the quality was low and the cost was high. After the formula was adjusted, the quality was improved and the cost was reduced by 575 yuan per 10,000 meters. From January to August of 1981, a total saving of 189,500 yuan was realized by changing the formula in the mill.

In 1981, the Yunnan mill completed 10 major improvement projects and promoted production development. The accumulative gross value of industrial production from January to October in 1981 was 109.51 million yuan at a profit of 11.66 million yuan, these figures represent respectively 21 percent and 10 percent increases over the same period in 1980.

Foreign Affairs Work Conference

Xian SHAANXI RIBAO in Chinese 18 Dec 81 p 1

[Article by Sun Jianquo [1327 1696 0948]: "Science and Technology Foreign Affairs Work Conference Held in Shaanxi Province"]

[Text] Shaanxi Provincial Work Conference on Foreign Affairs in Science and Technology was held from 8 to 11 December in Xian.

Participating in the conference were associated provincial level bureaus and committees, some colleges and universities, plants, scientific research units, and comrades from regional and municipal science committees. Deputy Governors Song Youtian [1345 0645 3944] and Li Lianbi [2621 6647 3880] attended the meeting. Li addressed the conference at its opening and some units described their experience on science and technology in foreign affairs.

Based on the actual situation, the conference began some solid and in-depth activities on the policy of learning from and absorbing foreign science and technology. After study, it was determined that the major assignments for 1982 activities in Shaanxi Province are: conscientiously carry out the work policy on foreign technology and serve the technological improvement in the national economy; draw up annual plans for international exchange and put them on a solid basis, organize solid and in-depth science and technology exchange activities; make a conscientious effort in applying and promoting the results of technology exchange; establish and perfect the necessary regulations on science and technology exchange; strengthen the rank on foreign affairs in science and technology and continuously improve the standard of the work; and improve management and leadership. The conference called for high spirited and active work under the leadership of the provincial party committee and the provincial government to further develop science and technological activities with foreign countries and to contribute to the enterprise of socialist modernization.

Agriculture Sciences Work Conference

Guangzhou GUANGZHOU RIBAO in Chinese 3 Jan 82 p 1

[Article by Tan Yizhang [6223 1837 1757] and Ye Lifei [0637 7787 5481]: "Guangzhou Municipality Held Agriculture Science Work Conference"]

[Text] "Speed up agricultural development on the basis of policy and science." A municipal agriculture science work conference was recently held by the municipal science committee jointly with the municipal agriculture committee to exchange experience on increasing production and accumulating wealth in the rural areas.

In recent years, Conghua County made a great effort to promote agricultural science knowledge in rural areas and to apply widely advanced agricultural technology. As a result, even though the actual rice planting area in 1981 was 5,900 mu less than in 1980 and there were severe natural misfortunes last year, the total grain production and yield per mu in 1981 have both exceeded the best record in history. Because of the timely instruction on disease and pest control by the technical staff of the Fei-e brigade of Taiping Commune in Conghua County, the farmers were aware of how to prevent rice blast (*piricularia oryzae*) and took timely preventive measures. As a result, they increased the production of early maturing rice by 200,000 jin.

At Yaotin Commune in Xinfeng County, attention was given to scientific farming and they persisted on planting hybrid rice for 5 years and each year increased their farming area and production. In 1981, 6,862 mu of early maturing and late maturing Zayou rice were planted. The yield per mu of early rice was 750 jin and the per mu yield of late rice was 600 jin.

Longmen County had an increase in grain production of 17 million jin in 1981, 8.7 percent higher than the 1980 production. All 14 communes in Longmen County broke their previous best record. Increase in soybean production was 1.6 million jin, increase in peanut production was 1.24 million jin more than the highest production level of 1974, sugarcane production is expected to increase by 200,000 dan [50 kilograms] and the rural population is expected to make 20 yuan more per person on an average.

In addition to following the policy, these developments in agricultural production are also closely related to the effort of broadly promoting agricultural science in the rural areas. Comrades from agriculture and science departments at the conference affirmatively recognized the results brought about by agricultural science efforts and requested people actively to create favorable conditions and make the agricultural science effort even more widespread and thorough and to make even greater contributions to the development of agricultural production.

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APPLIED SCIENCES

ELECTROMAGNETIC ROCKET IS SUCCESSFUL ON FIRST EXPERIMENTAL FLIGHT

Guangzhou NANFANG RIBAO in Chinese 26 Jan 81 p 4

[Text] The Electromagnetic Propulsion Laboratory of the Space Science and Technology Center of the Chinese Academy of Sciences has developed an electromagnetic rocket that recently successfully completed its first experimental flight in space, giving China a new type of microthrust rocket for its space vehicles.



Fig. 1. Technicians in a simulated vacuum environment conduct tests on electromagnetic rocket.



Fig. 2. China's first successful electromagnetic rocket. Characterized by slight thrust, high specific impulse, long life and good maneuverability and handling, it is well suited for various types of space craft and space shuttles for attitude control and orbital adjustments.

APPLIED SCIENCES

NEW DONOR IN ANNEALED SILICON STUDIED

Beijing DIANZI XUEBAO [ACTA ELECTRONIC SINICA] In Chinese No 6, 1981 pp 58-63

[Article by Xu Zhenjia [6079 2182 0857], Sun Bokang [1327 0130 1660], Wang Wannian [3769 8001 1628], Zhang Zehua [1728 3419 5478], Liu Jiangxia [0491 3068 1115] and He Guangping [0149 1639 1627]: "New Donor in Annealed Silicon (1)." Received June 1981]

[Text] Abstract

New donor generation in p-type CZ Si commonly used for LSI manufacture after annealing at 700°C has been studied. This new donor is confirmed to be closely correlated with oxygen impurity as is the thermal donor formed in 450°C annealing. However, the new donor differs greatly in annealing behavior from the thermal donor. The generation rate of new donor is slower than that of thermal donor, and the maximum new donor concentration after annealing for a long time (100 hrs) is about 10^{15} cm^{-3} . Impurity carbon promotes the generation of the new donor. The mechanism of new donor generation has also been briefly discussed.

As is well known, single silicon crystals containing oxygen produce donors, known as thermal donors (TD), after annealing at 650°C. The generation of thermal donors has large effects on the material stability and component quality. Therefore, the usual practice is to anneal the silicon material at 700°C to remove the thermal donors and to insure material and component quality. However, it was discovered recently¹⁻³ that after silicon is annealed at 700°C the resistivity drifts again due to the appearance of additional donors. Some call these donors the new donors (ND) to distinguish from the thermal donors (TD)². Obviously the generation of ND affects the material and device quality and the study of ND therefore has important practical significance. At present the investigation of ND is sparse and the understanding of the conditions, characteristics, and mechanism of ND generation is far from unified. The objective of this work is to investigate the existence, generation, characteristics, and mechanism of the new donor, and this paper represents some of the results of this study.

I. Experimental Technique

In order to study the fundamental properties of the new donor, we have annealed silicon single crystals from different sources at 700°C for different length of time. Most of the samples in our study are dislocation-free

p-type (boron doped) (100) CZ Si single crystals commonly used in LSI manufacture, its resistivity is $7 \sim 10 \Omega \cdot \text{cm}$. For comparison, we have also used FZ single crystals and CZ single crystals containing different amounts of oxygen and carbon. The range of oxygen content is $[O] = 10^{15} \sim 2 \times 10^{16}/\text{cm}^3$ and the carbon content is $[C] = 5 \times 10^{15} \sim 3 \times 10^{17}/\text{cm}^3$.

Before annealing, the samples are thoroughly cleaned. Annealing is carried out in a quartz tube in a common diffusion furnace. High purity (5N) argon gas is flowed through the quartz tube. The specimen is placed in a quartz boat and after annealing the quartz boat is pulled out of the furnace with a quartz hook and the sample is allowed to cool rapidly in argon gas. It takes a few minutes for the sample to cool from 700°C to room temperature. The accuracy of temperature control is better than $\pm 5^\circ\text{C}$ and temperature is monitored with a nanovolt digital voltmeter.

Before the annealed specimens are measured, the surface oxide layer (usually 300\AA) is etched away with hydrofluoric acid to remove the interference of SiO_2 and obtain bulk signal. Electrical measurements are made with the familiar Van de Pauw method by automated computer control and the sign and carrier concentration are obtained through Hall coefficient measurements. Optical measurements are made with a IFS115 Fourier spectrometer and a model PE599B infrared spectrometer. Sample preparation, experimental method and calculation of interstitial oxygen and substitutional carbon content have been described in detail previously. Losses of interstitial oxygen and substitutional carbon due to annealing are estimated from infrared absorption spectrum, i.e., $\Delta [O] = [O_0] - [O]$ and $\Delta [C] = [C_0] - [C]$, here $[O_0]$, $[C_0]$, $[O]$ and $[C]$ are respectively the oxygen and carbon contents before and after annealing. We use the percentages $\Delta [O]/[O_0]$ (percent) and $\Delta [C]/[C_0]$ (percent) to represent the loss of oxygen and carbon due to annealing.

II. Experimental results

1. Under the same annealing condition, there is considerable variation in carrier concentration after annealing for different samples, e.g., FZ single crystal or samples with widely different oxygen and carbon content. This result indicates that the new donor observed after the annealing at 700°C is not caused by contamination in the experimental process. In order to prove that the donor generated after extended annealing at 700°C is not TD, we first annealed the sample at 450°C for 40 hours to produce sufficient TD and then annealed it at 700°C for 1 hour. A typical result is shown in Figure 1. As can be seen, TD generated in the 40-hour annealing at 450°C is essentially eliminated after 1 hour annealing at 700°C . Hence, the donor state generated in subsequent long time annealing at 700°C is neither due to contamination nor the same as the TD generated at 450°C ; it is a new donor state, and we call it ND.

2. Figure 2 shows a typical growth curve of ND generated by annealing at 700°C for various lengths of time. For comparison, a growth curve of TD generated by annealing at 450°C for various lengths of time is also shown in Figure 2.

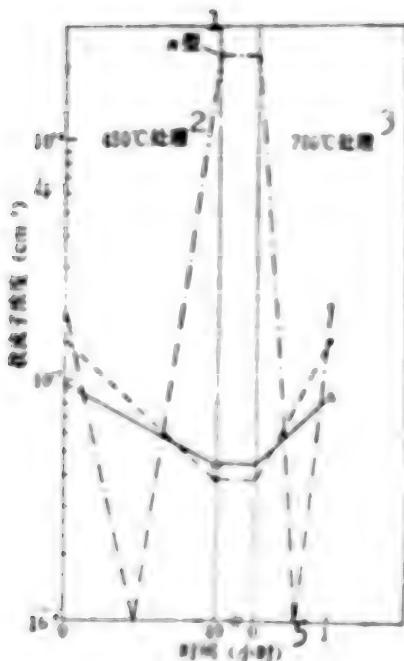


Figure 1. Generation and elimination of TD and generation of ND

Δ Si80-17-1 [O] = $1.3 \times 10^{16} \text{ cm}^{-3}$, [C] = $2.8 \times 10^{17} \text{ cm}^{-3}$
 ● Si80-11-4 [O] = $1.20 \times 10^{16} \text{ cm}^{-3}$, [C] = $8.4 \times 10^{17} \text{ cm}^{-3}$
 ○ Si80-13-4 [O] = $1.87 \times 10^{16} \text{ cm}^{-3}$, [C] = $1.5 \times 10^{17} \text{ cm}^{-3}$

Experimental points in the graph are hole concentrations unless stated otherwise.

Key:

- | | |
|--------------------|--------------------------|
| 1. n type | 3. 700°C annealing |
| 2. 450°C annealing | 4. Carrier concentration |
| | 5. Time (hours) |

As can be seen from Figure 2, the growth rate of ND is slower than the growth rate of TD. Λ and Λ' are respectively the growth rate of TD at 450°C and the growth rate of ND at 700°C for the same sample. For the same annealing time, the TD concentration is almost an order of magnitude higher than the ND concentration is almost an order of magnitude higher than the ND concentration. We also discovered the maximum value of the ND concentration [N_{ND}] to be $1.5 \times 10^{15}/\text{cm}^3$, which is an order of magnitude lower than that reported in Ref. (2). We observed no ND generation in specimens annealed at 700°C for a short length of time (10 hours), but 10 hours of annealing at 450°C produces a TD concentration of $10^{15}/\text{cm}^3$.

3. The relationship between ND and the oxygen impurity: we have shown⁵ in the past that no TD is generated in low oxygen content ($[O] = 10^{17}/\text{cm}^3$) CZ single

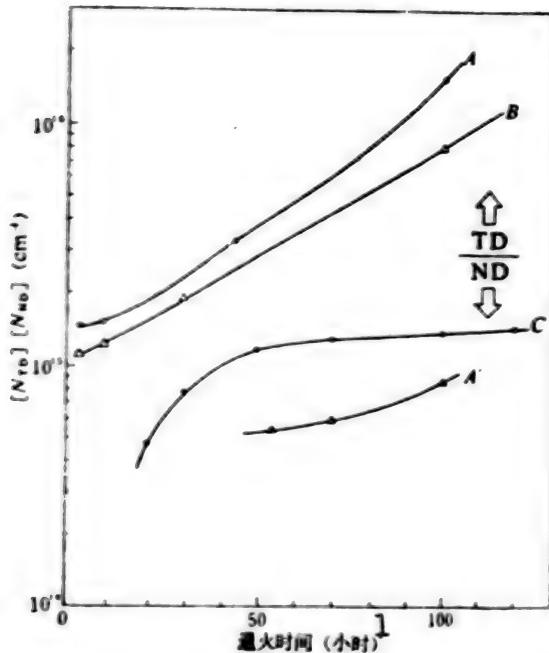


Figure 2. Comparison of TD and ND generation rate

A 和 A' Si79-4 $[O] = 1.5 \times 10^{18} \text{ cm}^{-3}$,
 $[C] = (2 \sim 3) \times 10^{16} \text{ cm}^{-3}$
 B Si79-9 $[O] = 1.3 \times 10^{18} \text{ cm}^{-3}$,
 $[C] = (2 \sim 3) \times 10^{16} \text{ cm}^{-3}$
 C Si80-17-1 $[O] = 1.3 \times 10^{18} \text{ cm}^{-3}$,
 $[C] = 2.7 \times 10^{17} \text{ cm}^{-3}$

Key:

1. Annealing time (hours)

2. And

crystals even after 100 hours of annealing at 450°C. For the new donor we discovered that no ND is generated in low oxygen ($10^{15}/\text{cm}^3$) FZ single crystals even after 120 hours of annealing at 700°C. For specimens with an oxygen concentration less than $5 \times 10^{17}/\text{cm}^3$, no ND generation is observed. For CZ single crystals with an oxygen concentration of $[O] = 1.5 \times 10^{18}/\text{cm}^3$ and a carbon concentration of $[C] = 1 \times 10^{16}/\text{cm}^3$ and $p = (N_A - N_D) = 1.9 \times 10^{15}/\text{cm}^3$, we observed $[N_{ND}] = 1.8 \times 10^{14}/\text{cm}^3$ after annealing at 700°C for 120 hours. It is therefore clear that a certain concentration of oxygen in the sample is a necessary condition for ND generation.

We have studied the dependence of $[N_{ND}]$ upon $[O]$ for a set of specimens containing $[C] = (1.3 \sim 3.0) \times 10^{17}/\text{cm}^3$ and the results are shown in Figure 3. As can be seen, $[N_{ND}]$ has a steep dependence on $[O]$. This seems to imply that there is a critical oxygen concentration for ND generation; when the oxygen concentration exceeds this critical value, a slight increase leads to considerable ND generation. For specimens with lower oxygen concentration, say $[O] = 3 \times 10^{17}/\text{cm}^3$, essentially no ND is observable after a long time (100 hours) annealing at 700°C.

For a given specimen, the relationship between ND concentration and the oxygen and carbon loss $\Delta[O]/[O_0]$ and $\Delta[C]/[C_0]$ is shown in Figure 4. As $\Delta[O]/[O_0]$ (or $\Delta[C]/[C_0]$) increases, $[N_{ND}]$ also increases. Statistical observations of

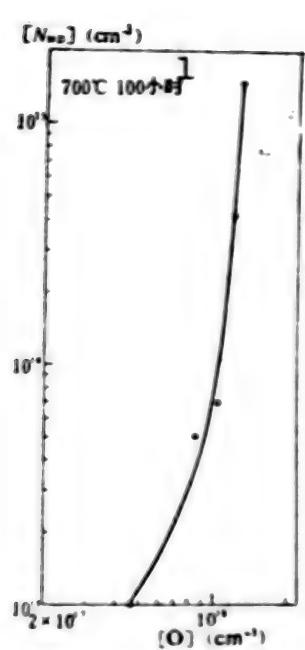


Figure 3. Dependence of ND concentration as a function of oxygen concentration.
 $[C] = 1.3 \sim 3.0 \times 10^{17} \text{ cm}^{-3}$

Key: 1. hours

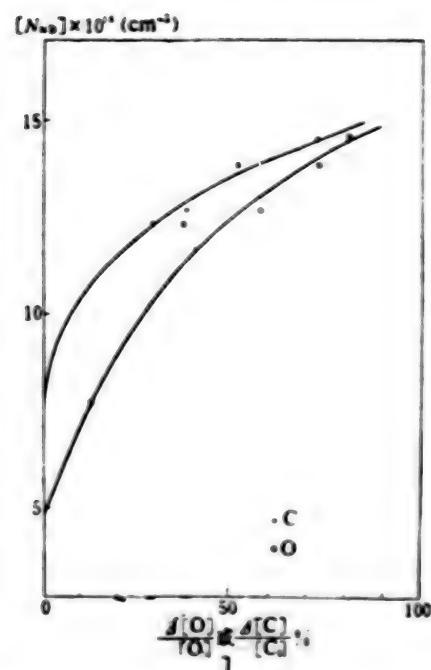


Figure 4. ND concentration as a function of oxygen and carbon loss in a given sample.
(Si 80-17-1, initial $[O] = 1.3 \times 10^{18} \text{ cm}^{-3}$, $[C] = 2.8 \times 10^{17} \text{ cm}^{-3}$)

Key: 1. or

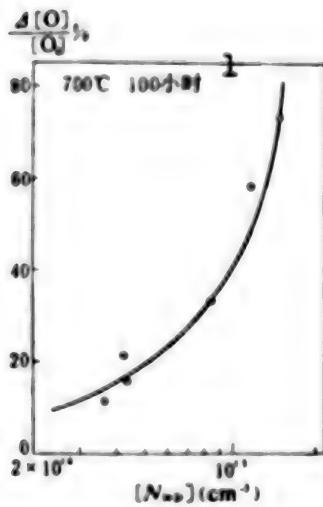


Figure 5. Relationship between ND concentration and oxygen loss in different samples. Initial $[O] = (1.2 \sim 2.0) \times 10^{18} \text{ cm}^{-3}$.

Key: 1. hours

different samples annealed for the same length of time have also revealed the fact that $[N_{ND}]$ increases as $\Delta[0]/[0_0]$ increases, as shown in Figure 5. The generation of ND is therefore closely correlated with the disappearance of interstitial oxygen. There are two ways for interstitial oxygens to decrease: Part of them may precipitate out as SiO_2 , for example. In our work we have observed such precipitants⁶ with sizes ranging from a few Å to 500Å. Part of the oxygens may transfer from interstitial sites to substitution sites. These two changes give rise to $\Delta[0]$. Thus the generation of ND may be related to both of these changes.

4. The relationship between ND and the carbon impurity

Previously we have shown⁵ that carbon impurity suppresses the generation of TD, as shown in Figure 6(a). In silicon wafers of equal oxygen concentration, as carbon concentration increases the thermal donor concentration $[N_{TD}]$ generated by annealing at 450°C for 100 hours decreases. For the new donor, however, the opposite is true; $[N_{ND}]$ increases as the carbon concentration increases in a set of silicon wafers of similar oxygen concentration. The dependence of $[N_{ND}]$ as a function of $[C]$ is shown in Figure 6(b). Due to the differences in thermal annealing time and specimen impurity and thermal history, it is rather difficult to establish a quantitative relationship. In our experiments on a set of samples with an initial oxygen concentration of $[0_0] = (1.2 - 1.9) \times 10^{18}/cm^3$ annealed at 700°C for 100 hours, there appears to be an approximate relationship of $[N_{ND}] \propto [C]^{0.87}$.

The relationship between $\Delta[C]/[C_0]$ and $[N_{ND}]$ has been shown in Figure 4. As the loss of substitutional carbon increases, the concentration of ND also increases. We have experimentally demonstrated⁶ that increases in carbon content promote the increase in $\Delta[0]$; in the meantime we have also observed that the change in $\Delta[C]$ by 700°C annealing is much greater than that caused by annealing at higher temperature (1,050°C). For example, after 100 hours of annealing at 700°C and 1,050°C, $\Delta[C]/[C_0]$ are respectively 50 and 15 percent.

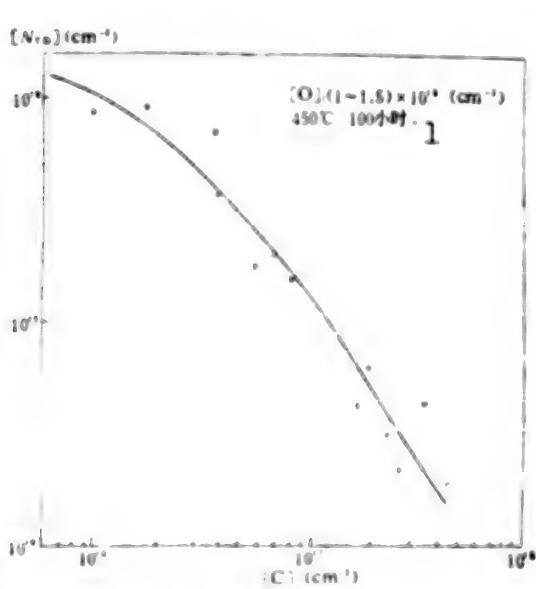


Figure 6(a). Relationship between thermal donor concentration and carbon concentration.

Key: 1. hours

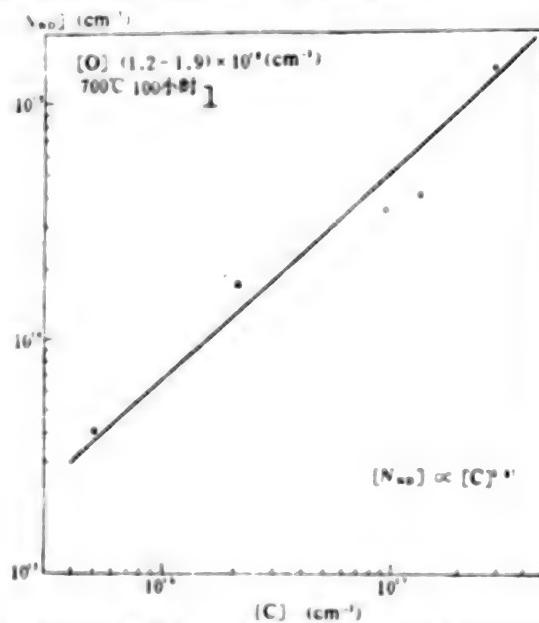


Figure 6(b). Relationship between new donor concentration and carbon concentration

Key: 1. hours

III. Discussion

1. Obviously the results we obtained differ from the conclusion of Grinshtain who believes that TD and ND are basically the same. We believe that although TD and ND have similar annealing characteristics, that is, they both need a certain concentration of oxygen impurity for their generation and they both increase with increasing oxygen concentration, but $[N_{TD}]$ is suppressed by the presence of carbon and $[N_{ND}]$ is promoted by the presence of carbon. Besides, both the growth rate and the maximum concentration of ND are lower than those of TD. Therefore we do not think it is desirable to interpret ND on the basis of the SiO_4 model used in the interpretation of TD such as a SiO_m ($m \neq 4$) model.

2. The generation of ND depends on a number of factors such as the thermal history of the specimen, including preannealing, the sign of the carrier (p-type or n-type), and the content of oxygen and carbon impurities. Although we have studied a large number of samples from different sources, some statistical relations still require further confirmation. For example, although we have observed that preannealing at $450^\circ C$ increases the growth rate of ND, some of the factors still need further exploration. After extensive work, we believe the effects of oxygen and carbon impurity discussed above are clear and reliable.

3. As for the generation mechanism of ND, there is yet to be a mature interpretation, and our work on this topic is continuing. However, our preliminary viewpoint is that oxygens occupy the interstitial sites O_i in silicon and carbons occupy the substitutional sites C_s . After annealing at $700^\circ C$, we noticed a pronounced increase in $\Delta[C_s]$, indicating that the silicon lattice is left with a large number of vacancies V_{Si} . Under the agitation of thermal motion, O_i may move to the position of V_{Si} and assume the role of a substitutional donor, just like the role played by the familiar III, V impurity elements. One can therefore imagine that O_i contributes one or two electrons and plays the role of a single donor or a double donor. Considering the discrepancy in O_i diffusion data in silicon,^{7,8} we feel that the simplified model of a simple substitutional donor OSi may be used in the interpretation of ND and it may not be necessary to use such large clusters as Si_xO_y . In this consideration, such phenomena as oxygen being a necessary condition for ND generation and carbon promotes the generation of ND can be understood. Obviously, we are making further studies on the detailed mechanism of ND.

4. At the present there is no doubt about the existence of ND. The resistivity drift⁹ after annealing at $700^\circ C$ may be interpreted in terms of ND. From an application point of view, the generation rate of ND is much slower than TD and short time (10 hours) annealing at $700^\circ C$ gives rise to very small N_{ND} . Therefore when we carry out $700^\circ C$ annealing to insure the stability and quality of silicon material, ND will not have a great effect as long as the annealing time is short. However, when the annealing time is long, the resistivity drift caused by ND generation must be closely watched, especially at the two ends of the single crystal where the oxygen and carbon contents are high.

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CSO: 4008/76

APPLIED SCIENCES

PRC HOLDS RADIATION, ISOTOPE APPLICATION EXHIBIT

OW111051 Beijing XINHUA Domestic Service in Chinese 10 Feb 82

[Text] Beijing, 10 Feb (XINHUA)--At the exhibition on the application of isotopes and radiation held during the National Isotope Conference, many visitors were attracted by an exquisite pair of miniature glasses on display. These new-type glasses for the nearsighted are made of materials treated with radiation. The device completely does away with the traditional frame and lenses and is soft and comfortable to wear as well as ventilative. Beijing Municipality Mayor Jiao Ruoyu was very interested in it. As soon as he returned from the exhibition, he asked the manager of the Beijing Municipal Spectacles Company to pay a visit to the exhibition and see how the device could be mass-produced as quickly as possible.

The device was only one of the nearly 100 items on display at the exhibition. In the first section of the three-section exhibition one could see various kinds of radioactive isotope preparations, radioactive medicines, a medical kit for radiation immunity analysis [Fang She Mian Yi Fen Xi 2397 1410 0346 4004 0433 2649] and various kinds of radiation units produced in China. According to the information provided by exhibition officials, domestically produced isotope products number more than 250 and are being supplied to over 1,200 customers throughout the country. The second section of the exhibition dealt with the results achieved in the application of isotopes and radiation in industry, agriculture and medical treatment. Items on display in this section included various kinds of fine-strain crops developed by using radiation; potatoes, onions and garlic that have preserved their freshness as a result of radiation treatment; and fresh meat and cooked foods that have retained their quality and have remained unspoilt after being kept under normal temperature for more than 2 months following radiation treatment. Public health Minister Qian Xinzhong sampled such radiation-treated food items while visiting the exhibition. He also advised public health departments to pay attention to sanitation inspection of these food items and to draw up hygienic criteria for them as soon as possible.

Among the items on display, there were also various kinds of isotope instruments and meters and various kinds of radiation detection instruments and radiation safety and prevention equipment. These included a highly sensitive fire alarm device using an isotope--Americium 241--a radiation counter for carrying out large-scale radiation immunity analysis in hospitals, an isotope static

eliminator, isotope devices for determining thickness and density, and other such devices of wide applicability.

The many items on display made it clear that there is a bright future in harnessing atomic energy to serve the national economy and the people's livelihood.

The exhibition has been viewed by Vice Premier Zhang Aiping of the State Council and responsible persons of the departments concerned Zhao Dongwan, Liu Wei, Wang Lei, Li Hujia, Zhang Zhenhuan and Zhu Guangya.

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APPLIED SCIENCES

ANTINUCLEAR RADIATION ELECTRONICS STUDIED

Beijing DIANZI XUEBAO [ACTA ELECTRONICA SINICA] in Chinese No 6, 1981 pp 87-95

[Article by Lai Zuwu [6351 4371 2976] of the Chinese Nuclear Electronics and Nuclear Detection Technique Society, CIE: "The Antinuclear Radiation Electronics--A New Branch of Electronics." Received October 1980, revised August 1981]

[Text] Abstract

With the advance of nuclear weapons, spaceborn nuclear propulsion systems and nuclear reactors, the problem of radiation environment has become more and more important during the last 20 years. Since the electronic devices and systems are quite sensitive to nuclear radiation, they must be well designed and hardened in order to operate and survive in space and near the nuclear reactor or the explosion of a nuclear weapon. So antinuclear radiation electronics has been formed and developed into a new branch of electronics. An outline of the so-called antinuclear radiation electronics would include three major categories: (1) radiation effects (to make radiation tests and to evaluate the survivability); (2) damage mechanism (to study the damage mechanism and to determine the failure modes); (3) nuclear hardening (to make the hardening design and fabrication techniques). An overview of the new specialty is presented in this paper.

Antinuclear radiation electronics is a new field with only a 20-year history and is developing rapidly. It has now become an independent branch of electronics and proliferated into other branches of electronics. It is formed through the overlapping and interaction of semiconductor and solid state physics, nuclear physics, and electronics. At present its principal scope of study includes the following three topics: (1) effects of nuclear radiation on electronic devices and systems, or, radiation effect; (2) how nuclear radiation affects electronic devices and systems, or, damage mechanism; and (3) how to make the electronic devices and systems withstand the effect of nuclear radiation, or, nuclear hardening technique.

Just like the environmental problem goes with the development of industry, the study of electronic technology suitable for the nuclear radiation environment is increasingly becoming a topic that requires serious consideration. The problem of antinuclear radiation must be taken into account in a number of electronic systems from nuclear weapons systems, space and aviation electronic systems, regular military electronic facilities such as radar, communication,

command control, computation and measurement, nuclear power facilities to the important civilian electronic system. In short, antinuclear radiation electronics is a developing field that has not yet gained maturity. The work on nuclear radiation hardening and its application to actual systems has just begun and, along with the development of science and technology, this new discipline will no doubt evolve into an even richer new content.

1. Effects of nuclear radiation environment on electronic systems

1. Nuclear radiation environment^{1,2}

(1) Nuclear explosion

Nuclear explosion produces shock waves, thermal radiation, nuclear radiation, nuclear electromagnetic pulses and radioactive fallout. Their distribution is different for a high altitude explosion and a low altitude explosion. X-ray and thermal radiation are easily absorbed by the atmosphere and shielding structure, shock waves mainly cause mechanical damages, radioactive fallout spreads over a very large area and its energy is gradually released over a long period of time. Therefore, as far as the instance of nuclear explosion is concerned, the radiation environments of interest to electronic systems are primarily the direct radiation of neutrons and γ -rays and the nuclear electromagnetic pulse (EMP).

The effect of the neutrons is mainly the permanent damage they can cause. The quantity of general interest is the neutron flux or the number of neutrons passing through a 1 cm^2 area. The threshold value for neutron damage to semiconductor electronic systems is approximately 10^{13} n/cm^2 . The radius for neutron damage is about 30 km (electronic systems operate in an electrically neutral state).

When the total dosage of γ radiation is great enough, it too can produce permanent damage and the threshold for damaging ordinary transistors is $\sim 10^6$ rad. However, γ is only of secondary importance as compared to neutron, so we will primarily consider the effects of neutron in permanent damage caused by nuclear radiation to electronic systems operating under electrically neutral condition in a nuclear explosion environment.

For γ radiation the important consideration is the effect of the dosage. An electrically charged electronic system has a damage threshold due to γ dosage of approximately $10^6 \sim 10^7$ rad/s (to cause severe interference and to cause malfunctions such as erasing the signals in storage and leading to erroneous logic). Hence, although the transient effects of γ ray is recoverable, the damage radius can be as large as several hundred kilometers.

The electromagnetic pulse produced by high altitude nuclear explosions is very intense over a large range, it may induce several hundred amperes of current on the outer skin of aerocrafts. Thus, if a small fraction of this strong electromagnetic field leaks into the electronic system because of poor shielding, it damages the electronic system, and its damage radius may exceed 1,000 kilometers.

Even if an electronic system is well shielded, when it is situated within several hundred kilometers of the nuclear explosion, the internal electromagnetic pulse (IEMP) and system electromagnetic pulse (SGEMP) caused by the strong γ radiation may still damage the electronic system.

At present there is not enough study of the damage of electronic systems by electromagnetic pulse, but because of the disastrous effects, it has now raised serious concern.

For nuclear explosions in the atmosphere, both the neutrons and the γ -ray are absorbed by the atmosphere and their radii of damages are respectively reduced to 1 km and 10 km. But the radius of electromagnetic pulse damage will be much greater.

In short, nuclear explosions seriously jeopardize electronic systems within their influence. They cause malfunctions in the control systems of guided missiles, spacecraft, and airplanes, and they may also interfere with ground radar and communication systems.

(2) Outer space

Artificial satellites and spacecraft traveling in space are bombarded by various high energy particles in outer space. Radiation in space comes mainly from cosmic rays, sunspot radiation and the inner and outer Van Allen belts surrounding the earth. In addition there are solar wind, aurora radiation, solar x ray, solar neutrons and radiation, and electromagnetic waves of extremely wide frequency spectrum, but these are of secondary importance.

Cosmic rays are particles of extremely high energy but very low flux. Sunspot radiation consists of primarily high energy protons (~ 30 MeV). The spots may last from a few minutes to several days, the flux is usually in the 10^7 particle/cm² sec range, and the total dosage per time is approximately $10 \sim 10^3$ R. The two ring-shaped radiation belts situated in the space above the earth's equator--the inner and outer Van Allen radiation belts--pose the greatest threat to spacecraft orbiting around the earth. The effect of outer space radiation on electronic systems is mainly an accumulative radiation effect. The electronic systems in an earth satellite receive more than 10^4 R of accumulated radiation dosage per year, and the exposed surface components receive even more.

(3) Nuclear-powered devices

Nuclear reactors used in spacecraft and nuclear submarines are generally small in volume; if the electronic equipment used for control and measurement are inadequately shielded, the effects of radiation cannot be ignored. Nuclear radiation from the reactor is primarily neutrons and γ rays, but they are different from those in a nuclear explosion environment. Here the main concern is the accumulative effect of the long-term sustained radiation. As nuclear power becomes a more and more important energy source, the effects of the radiation environment of nuclear-powered devices on electronic systems are also becoming increasingly prominent.

2. Effects of nuclear radiation on electronic systems³⁻⁷

The effects of nuclear radiation on electronic systems on the one hand depend on the type, energy and dosage of the radiation and on the other hand also depend on the elements, components, materials, structure, and circuit design of the electronic system. Generally speaking, semiconductor components are most sensitive to nuclear radiation, and they are also the most studied; but the effects on other electronic materials often cannot be ignored either.

(1) Semiconductor component

Table 1 shows the trend of operating parameter changes of commonly-used semiconductor components after radiated by nuclear radiation.

Table 1. Change of Operating Parameters of Common Semiconductor Components After Nuclear Radiation

部件类型 ¹	工作参数 ²	参数随辐射剂量大的变化趋势 ³	部件类型 ¹	工作参数 ²	参数随辐射剂量大的变化趋势 ³
PN结二极管 ⁴	正向电压 V_F 5	增大 10	结型场效应管 ²⁷	跨导 g_m 28	减小 31
	反向击穿电压 V_R 6	稍大 11		漏电流 $I_{DSS} (V_{GS} = 0)$ 29	32
	反向漏电流 I_R 7	增大 12		夹断电压 V_T 30	减小 36
	上升时间 T_R 8	增大 13	MOS场效应管 ³³	跨导 g_m 34	减小 37
	存贮时间 T_S 9	减小 14		阈值电压 V_T 35	增大 40
耗尽二极管 ¹⁵	峰值电流 I_P 16	稍减 18	可控硅器件 ³⁸	控制极触发电流 I_{CR} 39	增大 45
	谷电流 I_V 17	增大 19		短路电流 I_{SC} 42	减小 46
双极晶体管 ²⁰	电流增益 h_{FE} 21	减小 24	太阳电池 ⁴¹	开路电压 V_{OC} 43	减小 47
	反向漏电流 I_{CBO} 22	增大 25		最大可能的功率比 44	减小 48
	饱和压降 V_{CES} 23	增大 26			

* Because of doping distribution, high speed diodes with low breakdown voltages are insensitive to permanent effects

**Because of heavy doping, radiation effects are small

Key:

- | | |
|--|--|
| 1. Component | 15. Tunnel diode |
| 2. Operating parameter | 16. Peak current I_p |
| 3. Changes of parameter as
radiation flux increases | 17. Valley current I_V |
| 4. PN junction diode | 18. Slight decrease |
| 5. Forward voltage V_F | 19. Increase |
| 6. Reverse breakdown voltage V_R | 20. Bipolar transistor |
| 7. Reverse leakage current I_R | 21. Current gain h_{FE} |
| 8. Rise time T_R | 22. Reverse leakage current I_{CBO} |
| 9. Storage time T_S | 23. Saturation voltage drop V_{CES} |
| 10. Increase | 24. Decrease |
| 11. Slight increase | 25. Increase |
| 12. Increase | 26. Increase |
| 13. Increase | 27. Junction field effect transistor |
| 14. Decrease | 28. Transconductance g_m |
| | 29. Leakage current $I_{DSS} (V_{GS} = 0)$ |

[key continued]

[continuation of key--Table 1]

- | | |
|-----------------------------------|------------------------------------|
| 30. Pinch voltage V_p | 39. Gate firing current I_{GF} |
| 31. Decrease | 40. Increase |
| 32. Decrease | 41. Solar cell |
| 33. MOS FET | 42. Short-circuit current I_{SC} |
| 34. Transconductance g_m | 43. Open-circuit voltage V_{OC} |
| 35. Threshold voltage V_T | 44. Maximum power ratio |
| 36. Decrease | 45. Decrease |
| 37. Increase | 46. Decrease |
| 38. Silicon controlled components | 47. Decrease |

Table 2 shows the radiation damage tolerance limit of common semiconductor components.

Table 2. Tolerance Limit Against Radiation Damage of Common Semiconductor Components

編號 番号	品名 品名	中子 (電子) (n/cm ²)	γ 射線 (Co ⁶⁰) (rad)	質子 (~20MeV) (電子)/cm ²
8	低頻功率晶体管 ($f_c < 50\text{Hz}$)	$10^{10} \sim 10^{11}$	$10^6 \sim 10^7$	$5 \times 10^9 \sim 5 \times 10^9$
9	中頻晶体管 ($50\text{MHz} < f_c < 150\text{MHz}$)	$10^{11} \sim 10^{12}$	$10^6 \sim 10^7$	$5 \times 10^9 \sim 5 \times 10^{10}$
10	高頻晶体管 ($f_c > 150\text{MHz}$)	$10^{12} \sim 10^{13}$	$10^6 \sim 10^7$	$5 \times 10^{10} \sim 5 \times 10^{11}$
11	JFET	$10^{11} \sim 10^{12}$	$10^6 \sim 10^7$	$10^{11} \sim 10^{12}$
12	MOS 场效應管	$10^{12} \sim 10^{13}$	$\sim 10^7$	$10^{11} \sim 10^{12}$
13	晶體半導體元件	$10^{11} \sim 10^{12}$	10^7	
14	整流二極管	$10^{11} \sim 10^{12}$	$10^6 \sim 10^7$	$3 \times 10^{11} \sim 3 \times 10^{12}$
15	穩壓二極管	$5 \times 10^{11} \sim 5 \times 10^{12}$	$10^6 \sim 10^7$	$10^{11} \sim 10^{12}$
16	隧道二極管	$10^{11} \sim 10^{12}$	$> 10^7$	$10^{11} \sim 10^{12}$
17	單結晶体管	$5 \times 10^{11} \sim 5 \times 10^{12}$	$\sim 10^7$	$10^{10} \sim 10^{11}$
18	可控整流器	$< 5 \times 10^{12}$	$< 10^7$	
20	邏輯電路	$5 \times 10^{11} \sim 10^{12}$	$\sim 10^7$	10^{10}
21	光電電路	5×10^{11}	$\sim 10^7$	$\sim 10^{11}$
22	MOS電路	5×10^{11}	$\sim 10^7$	

Key:

- | | |
|--------------------------------------|--|
| 1. Component | 12. MOSFET |
| 2. Radiation | 13. Microwave semiconductor components |
| 3. Neutrons (fission) | 14. Diode rectifier |
| 4. γ -ray (Co ⁶⁰) | 15. Voltage stabilizer diode |
| 5. Protons (~20 MeV) | 16. Tunnel diode |
| 6. (Protons/cm ²) | 17. UJT |
| 7. Discrete component | 18. Silicon controlled components |
| 8. Low frequency power transistor | 19. Integrated circuit |
| 9. Intermediate frequency transistor | 20. Logic circuit |
| 10. High frequency transistor | 21. Linear circuit |
| 11. JFET | 22. MOS circuit |

Damaging effects of nuclear radiation to various semiconductor components are as follows: the tolerance limit of ordinary transistors to neutron damage is approximately 10^{13} n/cm², which is equivalent to the neutron flux 30 kilometers from a 1 megaton high altitude nuclear explosion. The tolerance limit of γ ray damage is 10^6 - 10^7 rad, equivalent to a 1 kilometer destruction radius. Therefore, the effects of the neutrons are considered only with respect to permanent damage to transistors caused by nuclear explosions. For transistors of the same material, high frequency transistors have a higher tolerance to radiation. For transistors of the same material and the same frequency response, low power transistors are more tolerant to radiation. For components of the same material and frequency, NPN transistors have better anti-radiation performance than PNP transistors. For a given material, diodes are more anti-radiation than triodes. For the same type of component, germanium transistors can stand radiation better than silicon transistors. UJT and silicon controlled components have the poorest anti-radiation properties: their tolerance limits are usually two orders of magnitudes lower than that of transistors. Microwave components are much better than ordinary transistors in anti-radiation, their tolerance limits are 1 to 2 orders of magnitudes higher. JFET's outperform bipolar transistors against neutron radiation, they can usually stand 10^{14} - 10^{15} n/cm² flux. MOSFET's are also somewhat better than bipolar transistors in anti-neutron radiation but they are quite sensitive to γ -ray: under 10^4 - 10^5 rad illumination, the threshold voltage V_T may drift several volts toward the negative direction. In general integrated circuits are better than discrete semiconductor components in tolerating radiation, their tolerance limit for neutron damage is 5×10^{13} - 10^{15} n/cm².

It should be pointed out here that because of the great variety of semiconductor components and the fact that effects of radiation not only depend on the type of radiation but also on the energy of the radiation, the data presented here are composite data, and they are only used in the qualitative interpretation of radiation effects and range of tolerance limit.

For transistors, the first consideration of γ ray effect is the transient photoelectric current induced by the γ ray dosage. In general when the dosage exceeds 10^6 rad/sec there will be noticeable photoelectric current induced in the transistor. Within a certain range, the photoelectric current is directly proportional to the flux of radiation and the storage time of the transistor also increases with increasing flux ($\propto \lg t$).

(2) Electronic material

The relative sensitivity of common electronic material to stable nuclear radiation is listed in Table 3. As can be seen, organic materials are easily damaged by nuclear radiation. That is, their mechanical strength and insulating ability are reduced as dissociation makes them discolored and brittle. Polytetrafluoroethylene may turn into powder after 10^5 rad of γ radiation. Inorganic insulators such as quartz, mica, glass and porcelain have a better resistance to radiation, and they may function under 10^{19} n/cm² neutron flux and an ionization dose of 10^9 rad.

Table 3. Tolerance Limit of Radiation Damage of Common Electronic Materials

材料 Material	2 照射率 照射率		中子 (1MeV) 3 (n/cm ²)	电离辐射 4 (rad)		材料 Material	2 照射率 照射率		中子 (1MeV) 3 (n/cm ²)	电离辐射 4 (rad)				
	1	2		3	4		5	6	7	8	9	10		
晶 体 5	$10^3 \sim 10^4$	$3 \times 10^3 \sim 3 \times 10^4$	玻璃 14	$10^4 \sim 10^5$	$10^3 \sim 10^4$	半 导 体 6	$10^4 \sim 10^5$	$3 \times 10^3 \sim 5 \times 10^4$	有 机 材 料 7	$10^4 \sim 10^5$	$10^3 \sim 10^4$	聚四氟乙 烯 8	$10^4 \sim 10^5$	$10^3 \sim 10^4$
玻 璃 9	$10^3 \sim 10^4$	10^3	石英 16	$10^4 \sim 10^5$	$10^3 \sim 5 \times 10^4$	云母 17	10^4 以上	$10^3 \sim 10^4$	塑 料 10	$10^4 \sim 10^5$	$10^3 \sim 5 \times 10^4$	聚乙 烯 11	$10^4 \sim 10^5$	$10^3 \sim 10^4$ 以上 22
橡 胶 12	$10^4 \sim 10^5$	$10^3 \sim 10^4$	磁性材 料 20	$10^4 \sim 10^5$	10^3	金 属 21	$10^4 \sim 10^5$	10^3	聚丙烯 13	$10^4 \sim 10^5$	$10^3 \sim 10^4$	金 属 22	$10^4 \sim 10^5$	10^3 以上 22

Key:

- 1. Material
- 2. Radiation
- 3. Neutron
- 4. Ionizing radiation
- 5. Crystal
- 6. Semiconductor
- 7. Organic material
- 8. Polytetrafluoroethylene
- 9. Resin
- 10. Rubber
- 11. Polyethylene
- 12. Polystyrene
- 13. Resistor material
- 14. Capacitor material
- 15. Mylar film
- 16. Quartz
- 17. Mica
- 18. Glass
- 19. Porcelain
- 20. Magnetic material
- 21. Metals
- 22. or more

Semiconductor material can withstand a neutron flux of $10^{13} \sim 10^{17}$ n/cm². Glass semiconductor has the best antiradiation property and suffers no noticeable performance degradation under a neutron flux of 10^{17} n/cm² or a γ -ray dosage of 2×10^{11} rad/sec. Silicon has a radiation tolerance of 10^{16} n/cm² and 10^8 rad. Metals are the best in withstanding radiation, and the change is primarily in the resistivity. For example, under a neutron flux of 10^{19} n/cm², the resistivity of wire-wound resistors increases only by a few percent. For high melting point metals such as tungsten and molybdenum the change is only a 10 percent increase and can be restored by annealing.

For insulating and filling material, the important thing is the transient effect, that is, the induced conductivity change. Induced conductivity is usually related to radiation dosage by the following equation:

$$\sigma = K \delta^{\lambda}$$

where K is a coefficient generally in the $10^{-20} \sim 10^{-16}$ S/cm/rad/s range and λ is approximately equal to 1 for most material.

(1) Other electronic components

Tolerances to radiation damage of other common electronic components are listed in Table 4 below.

Table 4. Tolerance Limit of Radiation Damage of Common Electronic Components

1 元器件类型	2 辐射类型	中子 ³	γ 射线 ⁴	电子 ⁵ (MeV)	质子 ⁶ (50MeV)
		(n/cm ²)	(rad/s)	(e/cm ²)	(P/cm ²)
电真空器件 ⁷		$10^{10} \sim 10^{11}$	$> 10^6$		
充气器件 ⁸			$10^6 \sim 10$ rad/s		
阻容元件 ⁹		$10^{10} \sim 10^{11}$	$10^4 \sim 10^5$ $R_{leakage} \approx 10^{10} / \dot{\gamma} (\Omega)^*$	10^{10}	10^{11}
石英晶体 ¹⁰		$10^{10} \sim 10^{11}$	3×10^7		
继电器 ¹¹		6.5×10^{11}	$> 10^6$		
高频电缆 ¹²			17. $I_{core} \approx 10^{-11} \dot{\gamma} (A)^*$		
13 太 阳 能 电 池	PN型 ¹⁴			10^{10}	10^{11}
	NP型 ¹⁵			5×10^{10}	5×10^{11}

说明：太阳能电池按功率退化50%考虑。¹⁶ $\dot{\gamma}$ rad/s 为单位。¹⁷

Key :

- | | |
|---------------------------------------|---|
| 1. Component | 12. High frequency cable |
| 2. Radiation | 13. Solar cell |
| 3. Neutron | 14. PN type |
| 4. γ -ray | 15. NP type |
| 5. Electron | 16. Leakage |
| 6. Proton | 17. Induced current I_{core} in 1 meter
of cable $\approx 10^{-11} \dot{\gamma} (A)$ |
| 7. Vacuum component | 18. Explanation: Assumed 50 percent
degradation in solar cell power |
| 8. Gas filled component | 19. * $\dot{\gamma}$ in unit of rad/s |
| 9. Resistive and capacitive component | |
| 10. Quartz crystal | |
| 11. Relay | |

Table 4 shows that ordinary resistive and capacitive components are more resistive to radiation than transistors by 2~3 orders of magnitude. However, when operated in the atmosphere, the main consideration of resistive and capacitive components is the induced leakage resistance $R_{leakage}$ caused by ionizing radiation. Under 10^6 rad/s, $R_{leakage}$ may drop below 100Ω . Vacuum tubes can also withstand more radiation than transistors can, by 2~3 orders of magnitudes. However, components with oxide coated cathode have poorer ability to withstand radiation and the effects of ionization must also be taken into account. When a cable is irradiated, current is generated in the cable core. For high frequency signal cables, the current induced in the cable core for 1 meter of cable is approximately $10^{-11} \dot{\gamma} (A)$, where $\dot{\gamma}$ is in unit of rad/s. Under 10^{10} rad/s illumination, the induced current may reach 0.1 A. For solar cells, the main consideration is the effect of high energy electrons and protons. After irradiation, the efficiency of the solar cell, the short-circuit current, open-circuit voltage, and power decrease. NP-type solar cells are better than PN-type solar cells in withstanding radiation.

At first, attention to the effect of nuclear electromagnetic pulse on electronic systems was limited to the effects on electric wave propagation and radio communication due to ionosphere disruption caused by high altitude nuclear explosions. It was discovered later that electromagnetic pulse may cause direct and serious damages to electronic systems. It can lead to severe electrical interference, breakdown and melting of components and the influence may reach several hundred kilometers. Naturally the degree of damage by nuclear electromagnetic pulse depends on the electromagnetic shielding employed by the electronic system, hence missile silos are all equipped with electromagnetic shielding. For situations where tight shielding is not possible, the effect of nuclear electromagnetic pulse is no less than that of nuclear radiation. Moreover, the so-called system generated electromagnetic pulse (SGEMP) and internal electromagnetic pulse (iEMP) produced by strong γ rays directly impinging on the shell or the cavity of the shield cannot be prevented by shielding. For this reason, investigation of the internal electromagnetic pulse (including system generated) and study of prevention methods have attracted wide attention.

II. Principal topics of study⁸⁻¹⁵

Because semiconductor components are most sensitive to nuclear radiation and are also the most widely used components, the study of radiation effects of semiconductor components played a principal role in the entire investigation of radiation effects. Radiation sources used in the study are mainly neutron, γ -ray, proton, electron and electromagnetic pulse. From the point of view damage radiation effects may be divided into permanent damage, transient damage, and semipermanent damage. With radiation source and radiation effect both taken into account, one can say that the main concern for neutron damage is permanent damage; for γ -ray it is transient and semipermanent damage (of course, permanent damage caused by prolonged irradiation of large γ -ray dosage is also important); for ionizing radiations such as protons and electrons the main concern is semipermanent and permanent damage; for electromagnetic pulses we are concerned with both transient effect and permanent damage.

In the study of radiation effects, one should select the most important, sensitive, and representative parameter as the characteristic quantity of damage. For instance, for bipolar transistors the characteristic quantity is usually the common-emitter current gain h_{FE} . Since $\Delta(1/h_{FE})$ is usually directly proportional to radiation flux ϕ , or, $\Delta(1/h_{FE}) = K \phi$, the damage coefficient K is a good characteristic quantity. An alternative method is to define a damage threshold and phenomenologically characterize the radiation tolerance limit of a certain component.

The transient radiation effect is mainly recognized by the appearance of induced photoelectric current. For dosages less than 10^9 rad/s, the induced photoelectric current is directly proportional to radiation dosage rate; exceeding this range, some components may generate anomalous photoelectric current.

Because different types of radiation and radiations of different energy may produce different damage, an investigation of the equivalence relationship of different types of radiation and radiation of different energy has also begun.

Although radiation effects of the components form the basis of radiation effects on the entire electronic system, radiation effects of the circuits must also be studied. Although the radiation may have exceeded the tolerance limit of some individual components, the circuit as a whole may still function normally; conversely, the radiation level may be within the tolerance limits of individual components but, due to their mutual interaction and the effects of the electronic material, the entire circuit may no longer be operational.

At the present, investigation of the radiation effects on integrated circuits has been the principal content of radiation studies of electronic systems. Generally speaking, the radiation effect on each active component in an integrated circuit is less than that on discrete components. Passive components are also affected by radiation however. In addition, parasitic junctions and parasitic transistors between various elements and components may lead to transient photoelectric current and thereby change the operating condition, even to total failure. Locking phenomenon is the main cause for integrated circuit failure.

For an actual circuit, the analysis of radiation effect is often complicated. The present trend is to establish physical and mathematical models for radiation effects and then use computers to carry out auxiliary design. The most widely used model for transistor circuits is the Ebers-Moll model. Some new model has also been proposed, but is often less than satisfactory and needs to be progressively modified through experimentation. Often used computer programs include ECAP, SCEPTRE, CIRCUS, TRAC and NET-1.

2. Damage mechanism

In the study of damage mechanism, one investigates how the various types of radiation cause damage to electronic elements, components and systems. It is the theoretical basis for analyzing radiation effects, establishing mathematical model and conducting nuclear hardening. It has a very wide scope of study. It is now basically understood that there are three major damage mechanisms leading to radiation damage of semiconductors. They are displacement effect, ionization effect, and surface effect.

(1) Displacement effect

This refers to the fact that, through the interaction between the radiation particle and the atom in the crystal, the atom acquires sufficient energy to move away from its original position on the lattice. In most semiconductors the threshold value for lattice atom displacement is 10~25 eV. High energy radiation particles interacting with lattice atoms can easily lead to atom displacement and produce defects. Acting as recombination centers, the defects decrease the life of minority carriers in the base and thereby reduce the current gain of the transistor.

High energy neutron, γ -ray, proton and electron can all produce displacement and lead to similar changes in characteristics. However, the microscopic processes of producing displacement are different for different types of radiation.

Ionizing radiation (protons, electrons, γ -ray) transfers its energy to the atoms primarily by Coulomb scattering. The displacement defects it produces are point defects of uniform distribution. Neutrons are electrically neutral and transfer their energy mainly by elastic collision which has a small probability but transfer greater amounts of energy. A 1 MeV neutron on average transfers 72.5 keV of energy per collision with an atom. Compared to protons and electrons of equal energy, this energy transfer is several hundred times greater. High energy neutrons produce groups of defects in semiconductors, each group containing 200 - 1,000 defects.

Radiation-induced defects may interact with existing impurities and oxygen interstitials in the crystal to form various composite defects. At room temperature single defects are unstable and defect groups and composite defects can also be annealed out at elevated temperatures. They may also vanish or form new defects. For example, the temperature for complete annealing of neutron-irradiated N-type silicon is 600 - 700°K.

The objective of studying the microscopic process of the damage mechanism is to gain better understanding of how the radiation-induced damage can lead to changes in basic macroscopic characteristics such as carrier density N , mobility μ and lifetime τ in semiconductor material and thereby affect its electrical properties.

The existence of these defects has been confirmed and observed through various experimental methods and their type and energy levels are also measured. Much of the theoretical work involves energy level calculation which serves to interpret the rules of radiation damage and guide the work of nuclear hardening. Through such research, one can basically explain how the defect and defect group introduce additional energy levels in the band gap and, acting as recombination centers and scattering centers, reduce the carrier life τ and mobility μ . They may also act as traps and change the carrier density.

At present defect study is a hot topic but there are still many details to be clarified. Because real situations are very complex, theoretical calculations often make many simplifications and can only do qualitative and semiquantitative analysis.

(2) Ionization effect

Ionizing radiations can produce excessive electron-hole pairs in semiconductors and change the conductivity; when the radiation source is removed, the conductivity recovers to its original value. In the presence of an electric field, these excessive electrons and holes move toward the positive and negative electrodes respectively and produce photoelectric current. In general the performance of the component is noticeably affected only when the excessive carrier concentration approaches the concentration of the original doping. Ionization effect is the principal mechanism for producing transient photoelectric current. Such photoelectric current can produce disturbance and affect the normal operation of the circuit.

(3) Surface effect

The surface effect here refers to the ionization produced in the surface oxide layer by ionizing radiation. It can lead to the results given below:

(1) Electron-hole pairs are produced by the ionizing radiation in the oxide layer, since the electron mobility is much greater than the hole mobility, under the influence of an external electric field the electrons flow toward the anode but the positive charges tend to accumulate on the SiO side of the Si-SiO₂ boundary. The buildup of positive charge can cause a polarity (type) change at the surface of the semiconductor, form a conduction channel, increase the surface recombination rate and the width of the space charge zone, reduce the common-emitter current gain, increase the reverse current and the junction capacitance and can shift the C-V characteristics toward the negative direction in MOS devices. (2) It may introduce surface states (surface defects) which can undergo charge exchange with the semiconductor. Both of these results can affect electrical properties. The processes in the surface effect are quite complicated, and both the theoretical work and experimental work in this area are yet to gain maturity.

3. Hardening studies

The hardening of electronic systems against radiation is the heart of the entire antiradiation electronics and the hardening of semiconductor components is the basis for the entire electronic system hardening. Today there has been great progress made in the hardening technology and a set of preliminary design criteria has emerged. Hardened systems may sustain radiations 2-3 orders of magnitude stronger. For convenience we divide our discussion of hardening into the following areas:

(1) Hardening of discrete semiconductor components

For different types of components there are different methods of hardening. Based on current research results, the hardening of components is conducted in the following areas:

i) Choosing materials with high tolerance to radiation--In principle, materials with short carrier life or high impurity doping (i.e. low resistivity materials) should be used. Performance of germanium, gallium arsenide, and silicon has been compared, and research on developing new glass semiconductor material has also begun. On the whole, silicon is still the principal material used today.

ii) Improving structure design--The principal criteria are: shallow junction, thin base structure, doping the base with gold, small dimension (especially the junction area), and maximum gain and bandwidth.

iii) Investigating inactivation technology--There have been studies on Al and Cr doping of SiO₂, new processing technology for pure SiO₂ and inactivated layer in Al₂O₃ and SiO₂+SiN₄. Results of these studies have shown that all of the above are successful to some degree and that the effects are different for n-channel and p-channel devices. In the beginning doping of SiO₂ was considered most promising, but the present belief is that for n-channel and p-channel compensated CMOS used in LSI, pure SiO₂ is still the best choice.

iv) Screening methods--Electrical parameter screening and radiation annealing screening have both been employed; the former is more straightforward and the latter is more effective.

(2) Hardening of unit circuits

A number of compensating circuits have been developed to reduce the effects of nuclear radiation on electronic circuits. The most commonly used circuits include Darlington circuits (for compensating gain degradation due to neutron radiation), transistor pair circuits (for compensating transient photoelectric current), collector impedance compensation circuits, base-to-emitter impedance compensation circuits, and emitter load compensation circuits. In order to achieve compensation, the components must have identical characteristics. Therefore, in actual practice these compensation circuits require repeated testing before they can be finalized.

(3) Hardening of integrated circuits

In principal, the hardening of integrated circuits is the same as that of discrete components. However, special problems exist in the hardening of IC's, namely, the problems of transient photoelectric current and locking caused by parasitic junctions and parasitic transistors must be solved. At present, the following IC hardening methods are available: (i) using medium isolation instead of junction isolation; (ii) using thin film resistor instead of diffused resistor; (iii) operating the reverse-biased junction at low voltage wherever possible; (iv) using compensation circuit or resistance to compensate or dissipate photoelectric current; (v) making the dimensions as small as possible; (vi) doping the base with gold impurity; and (vii) performing pre-irradiation with neutrons (to increase defects).

(4) Hardening of electronic systems

Different hardening practices are used for different electronic systems and application environments; however, from the viewpoint of hardening design of electronic systems, the following efforts should generally be made: (i) analyzing the nuclear radiation environment in which the systems will be used; (ii) giving the entire system overall consideration to locate the weaknesses and to conduct equilibration and hardening; (iii) selecting the elements and components according to the need, determining the radiation tolerance and necessary hardening of the selected components; (iv) designing anti-nuclear radiation circuits. Examples here are using various compensation circuits and high gain circuits, avoiding active components and high value resistance whenever possible, reducing the power dissipation of the circuit and improving the versatility of the logic. Because of the complexity of actual circuits, the assistance of computer analysis is generally required.

In designing the entire system, consideration should also be given to shielding structures (for reducing nuclear radiation and electromagnetic pulse), electronic materials (insulation and filler), and reliability. To improve the system reliability, a temporal avoidance method is often used, that is, the circuit is locked or shorted out during the idle period to avoid the

interference of transient photoelectric current and electromagnetic pulse caused by nuclear radiation during this period. For portions of the circuit that are easily damaged, duplicate circuits are often used.

III. Major technical problems involved

Since antinuclear radiation electronics is a science of studying how the electronics systems may service and function in a nuclear radiation environment, it naturally involves a series of technical questions in electronics and nuclear science. Due to the limited space, we shall only briefly discuss the following nuclear techniques.

1. Radiation source of the experiment^{16,17}

Nuclear radiation sources are needed to conduct experiments on radiation effect. Experiments may be conducted on site or under simulated conditions, and they complement each other; however, extensive experiments must be carried out using simulated sources. We now briefly introduce the major simulation sources.

- (1) Neutrons from fission spectrum--The most suitable source is a reflectionless, bare metal, highly concentrated uranium alloy pulsed reactor. Such a reactor may be operated under pulsed ultratransient critical state and it may also be operated under critical state.
- (2) High energy neutron (14 MeV)--Produced by various high-yield D-T reaction neutron generators.
- (3) Low energy and intermediate energy neutrons--Using TRIGA model pulsed reactor or neutron reactor.
- (4) Pulsed γ -ray source--High current pulsed electron beam accelerators are most suitable. Today there is also the "generator and transmission line dodecatron" which is most appropriate for transient γ irradiation experiments. In addition, electron linear accelerator can also be used; it produces high energy γ -ray but the dosage rate is low.
- (5) Accumulative dosage γ source--Co⁶⁰ source pulsed reactor are generally used.
- (6) High energy protons (several tens of MeV)--Usually from proton linear accelerator or cyclotron.
- (7) High energy electrons--Pulse electron beam accelerator or electron linear accelerator can often be used.
- (8) Electromagnetic pulse simulator--There are two types of simulator, the radiating type and the closed type. The radiating type is primarily used in the testing of communication radar systems in the fields and the closed type is used in testing components and small systems in the laboratory.

2. Experimental technique for studying accumulated radiation effect and damage mechanism

Experimental techniques in semiconductor physics, solid state (crystal) physics and nuclear physics are used extensively. For example, measurement of macroscopic parameters makes use of the usual semiconductor testing techniques (resistivity, capacitance, Hall mobility, C-V characteristics, and gm-V characteristics) in determining the lifetime, concentration and mobility of carriers, surface charge density, surface potential and recombination rate at the surface. Various transistor parameter measurements are also used in determining the value of relevant parameters. For studying the microscopic process of damage mechanisms, common experimental techniques of solid state physics (such as electron microscopy, the X-ray appearance technique, spectrum analysis, infrared absorption, electron spin resonance and electron ferromagnetic resonance) are used in observing the defects, establishing the defect type and measuring the energy level of the defect. The thickness, density, and distribution of defects are also studied by techniques of nuclear physics such as back scattering, channeling effect and Mossbauer effect.

3. Experimental techniques for studying transient radiation effect

When high current pulsed electron beam accelerators are used in the study of transient effect, the following problems must be solved in order to obtain good results: (1) anti-interference (including interference directly produced by strong γ -ray, EMP interference, and ground current interference); (2) acquisition and transmission of multiple signals; and (3) automatic data processing.

4. On-site measurement technique for nuclear explosions

For radiation effect experiments at the nuclear explosion site, the following problems must be solved: correct selection of measurement range and accurate determination of dose received by the sample, measurement technique for single and mixed fields (i.e. distinguishing the radiation effects due to neutrons, γ -ray and thermal radiation) and techniques for recovery (in accumulated effect experiment) and transient measurement (same as 3).

5. Computer analysis and design technique

IV. Conclusion

Research of the radiation effects on electronic materials and devices has been going on for more than 2 decades in foreign countries. In the 1950's, the emphasis is on the study of radiation damage to materials. Interests of research in the 1960's are radiation effects of semiconductor devices and the damage mechanism of materials. The attention in the 1970's has switched to the hardening of components and the design of actual circuits. The trend today is the development of practical nuclear radiation-hardened, very large integrated circuits and the theoretical prediction and promotion of such technique to civilian systems.

In the area of nuclear radiation hardening, work in the beginning stage emphasized the search for shielding materials that are capable of reducing the radiation effects and the subsequent hardening measures for electric circuits. Later the emphasis was gradually shifted to the technological improvement of electronic element and component structure. By early 1970's, the attention was shifted to the actual circuit development of electronic systems in pioneering weaponry and later extended to electronic systems in surveillance satellites, warning systems, communication systems, and strategic bombers.

The problem of nuclear electromagnetic hardening received attention in the late 1960's because transistors, IC's, and magnetic storage are very sensitive to electromagnetic pulses. Sometimes a dilemma arises concerning the hardening against electromagnetic pulse and against nuclear radiation. The former requires the system to have as narrow a frequency bandwidth as possible whereas for the latter a frequency bandwidth as wide as possible is preferred. They must be weighed with overall hardening design taken into consideration.

As to the study of semiconductor device hardening, work is progressing on both bipolar and MOS devices and good results have been obtained. Judging from developments, hardened MOS IC's are likely to be widely used in the future; however, hardened bipolar IC's are still playing the major role today.

Bipolar devices are more resistive to steady γ radiation but they are easily affected by neutrons. Hence, the hardening of bipolar devices primarily uses the technique of alternating multilayer metallization and the neutron radiation can be improved by 2 orders of magnitude. I²L device has some potential for nuclear hardening, with the new technique of ion implantation, the tolerance limit may reach 10^{14} n/cm² for neutron radiation, 10^6 rad for total γ dosage and 10^{10} rad/s for γ dosage rate.

MOS IC's are not sensitive to neutron radiation but very sensitive to γ ray because the gate, the drain, and the source are all on the surface. Under the illumination of ionizing radiation, its threshold voltage may drift. Therefore, the present emphasis for hardening is CMOS. The most effective hardening technique is silicon epitaxial on sapphire. In addition, ion implantation technique is also used in the precision control of doping in the P region and the N region and in controlling the introduction of oxide traps. The tolerance against neutron radiation for CMOS/SOS already developed has reached 10^{15} n/cm², for γ dosage the limit is 10^6 rad and for γ dosage rate the limit is 10^{10} rad/s.

CMOS-SOS and I²L are both considered to be most promising in nuclear hardening and in future application, but both are still in the research and development stage. It is anticipated that they will be improved and perfected in the 1980's.¹⁸⁻²⁰ The tolerance limits of CMOS/SOS are expected to reach $10^{15} \sim 10^{16}$ n/cm² for neutron, $10^6 \sim 10^7$ rad for γ dosage and $5 \times 10^{10} \sim 1 \times 10^{11}$ rad/s for γ dosage rate. For I²L, the corresponding tolerances are expected to reach $10^{14} \sim 10^{15}$ n/cm², $10^6 \sim 10^7$ rad and $1 \sim 5 \times 10^{10}$ rad/s.

An important trend is also emerging today, namely, the interest in nuclear hardening of electronic devices is shifting more and more from the military to the civilian field. This is because, on the one hand, civilian usage is also

beginning to require nuclear hardening and, on the other hand, the hardening technology has promoted the improvement of device performance. It can be anticipated that nuclear hardening technology will enjoy an accelerated development if it is increasingly applied to civilian electronics products.

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9698
CSO: 4008/75

APPLIED SCIENCES

HENAN CONFERENCE OF BROADCASTING BUREAU CHIEFS

HK130533 Zhengzhou Henan Provincial Service in Mandarin 1100 GMT 12 Feb 82

[Excerpts] The Henan Provincial Broadcasting Affairs Bureau convened a meeting of prefectural and municipal broadcasting bureau chiefs in Zhengzhou from 5 to 10 February. Provincial CCP Committee Secretary Zhang Shude, Provincial CCP Committee Standing Committee member and Propaganda Department Director Song Yuxi and Deputy Director (Wang Yu) attended the conference. Zhang Shude and Song Yuxi made speeches.

The conference pointed out: Rural wired broadcasting is a major medium for publicizing the building of socialist material and spiritual civilization. It is an important medium that other propaganda media cannot replace. The party committees at all levels and their propaganda departments must strengthen leadership over wired broadcasting. It is essential to take effective steps to improve the wires and loudspeakers in view of the gravely dilapidated state of the grassroots wire network and the serious decline in the number of loudspeakers.

The conference held: Henan has now initially built up a rural wired broadcasting network, thanks to the efforts of various sectors over many years. At present the province has completed 80 percent of the task of erecting wires from the county seats to the communes and 65 percent of the task of erecting wires from the communes to the production brigades. There are over 7.2 million loudspeakers. At present all municipal and county broadcasting stations proceed from reality and broadcast their own news, general knowledge, literature and art and service programs in addition to relaying the important programs of the central and provincial stations. The propaganda role of broadcasting in building socialist material and spiritual civilization is becoming ever more evident.

The conference proposed: The task for rural wired broadcasting in 1982 is to put propaganda work in the primary position, and grasp publicity in building socialist material civilization with one hand and publicity in building socialist spiritual civilization with the other. We should make full use of existing equipment and facilities, tap potentials and carry out innovations, and make big efforts to improve broadcast quality. At present we must pay particular attention to straightening out the grassroots networks. It is necessary to improve and strengthen maintenance and management of the network, set up sparetime maintenance organizations and put them on a sound basis, and solve the problem of the remuneration of maintenance and management personnel in a rational way. We should also get a good grasp of building broadcasting wires.

APPLIED SCIENCES

XIAN LASER PLANT IMPROVES PRODUCTS, MAKES PROFIT

OW180845 Beijing XINHUA Domestic Service in Chinese 0043 GMT 16 Feb 82

[Excerpts] Xian, 16 Feb (XINHUA)--The Xian Laser Instruments Plant has continued to turn out new products by strengthening coordination between manufacturing and scientific research units on one hand users on the other. Thus, its products have gained popularity with every passing day. At present, products manufactured by this plant are being used in 28 provinces, municipalities and autonomous regions. The Xian Laser Instruments Plant mainly turns out laser equipment for physiotherapy.

The aforementioned coordination has quickened the pace in pushing products through pilot plants and thus resulted in quickly turning scientific research achievements into industrial products. During the past 3 years the plant has successfully trial-produced 11 new products, including helium-neon laser needles, machines and reflectors for physiotherapy, a helium-neon laser generator for teaching purposes and a dual-tube helium-neon laser therapy machine. Three of these products have won provincial and municipal science awards.

To verify the efficiency and quality of its products, the plant has sent them to a number of hospitals with which it is maintaining cooperation, and has continuously improved on the products on the basis of users' opinions. As a result, its products have enjoyed good reputation and won full confidence from the users. The plant has been able to develop its production while increasing output and improving product quality. Since 1979, profits turned over to the state by the plant have increased by more than 20 percent each year.

CSO: 4008/102

APPLIED SCIENCES

BRIEFS

TIANJIN FOREIGN TECHNOLOGY CLASSES—Training classes for cadres to study policies, technological and economic theories and relevant knowledge on importing foreign technology with foreign capital opened today. The classes are jointly sponsored by the Tianjin Economic Commission, the Municipal Import and Export Commission and the Municipal Scientific and Technological Association. Mayor Hu Qili attended the opening ceremony and spoke. [SK211245 Tianjin City Service in Mandarin 1430 GMT 19 Feb 82]

CSO: 4008/103

Engineering

AUTHOR: CHENG Gengdong [4453 5105 2639]

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TITLE: "Optimum Design of Thin, Solid, Elastic Plates"

SOURCE: Dalian DALIAN GONGXUEYUAN XUEBAO [JOURNAL OF DALIAN INSTITUTE OF TECHNOLOGY] in Chinese No 2, 1981 pp 1-11

TEXT OF ENGLISH ABSTRACT: The present paper is a summary of our recently published research on the optimum design of thin, solid, elastic plates. Within the context of thin plate theory, we first study the traditional formulation for optimal design, and then proceed to a new formulation, which is based on a densely, integrally stiffened plate model. Both numerical and analytical results reveal that a global optimal thickness function for thin, solid, elastic plates does generally not exist within the class of continuous functions or continuous functions with a finite number of discontinuities, and should instead be sought within the class of functions with an infinite number of discontinuities. In cases where smooth (or partially smooth) designs are possible, a new necessary condition for optimality should be applied.

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TITLE: "A New Approach to Displacement Constraints in Multi-level Substructuring Method"

SOURCE: Dalian DALIAN GONGXUEYUAN XUEBAO [JOURNAL OF DALIAN INSTITUTE OF TECHNOLOGY] in Chinese No 2, 1981 pp 13-22

TEXT OF ENGLISH ABSTRACT: In this paper, a new efficient approach to treating the displacement constraints in analyzing a hierarchy of substructural modules by the displacement method is described. The concepts of the element and the superelement are to be distinguished from the concepts of the element module and the substructure module respectively. The approach is different from the current ones, in elements as well as superelements used instead of substructure modules, both the constraint of the master-slave relationship of displacements between various nodes and the forced boundary conditions corresponding to the displacements assigned a zero value can be applied, and the forced boundary conditions corresponding to the displacements assigned non-zero values can be applied as well. The displacements assigned non-zero values are all excluded from the global displacement vectors for substructure modules individually.

[Continuation of DALIAN GONGXUEYUAN XUEBAO No 2, 1981 pp 13-22]

By using the approach described in this paper, it will be convenient to deal with various displacement constraints in complex structures automatically. As a result, the computational effort and the core memory to be taken will be reduced considerably, the ill-condition of the global stiffness matrix will be avoided and the accuracy can be assured.

The approach described has been implemented in JIGFEX.

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TITLE: "Quasi-conforming Cylindrical Shell Elements"

SOURCE: Dalian DALIAN GONGXUEYUAN XUEBAO [JOURNAL OF DALIAN INSTITUTE OF TECHNOLOGY] in Chinese No 2, 1981 pp 23-30

TEXT OF ENGLISH ABSTRACT: In this paper a method is proposed to construct cylindrical shell elements in terms of the Quasi-conforming Element techniques. Some 20 parameters of rectangular elements for the cylindrical shell are provided. These elements have the advantages of better convergence, simpler formulation, less computing effort and satisfying rigid body displacement modes, thus they are worth practical purposes.

In the second and third sections a discussion is given of how to improve the accuracy of the element if the degree of freedom in an element is not increased. Finally, some computing results from the cylindrical shell elements are given.

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TITLE: "Investigation of Diesel Spray Photos by Stroboscopic Method"

SOURCE: Dalian DALIAN GONGXUEYUAN XUEBAO [JOURNAL OF DALIAN INSTITUTE OF TECHNOLOGY] in Chinese No 2, 1981 pp 31-36

TEXT OF ENGLISH ABSTRACT: The principles, peculiarities and applications of stroboscopic photographic apparatus are described in detail in this work. Stroboscopic photographic apparatus consists of a control system and a stroboscopic source which has a short-term stroboscopic effect and large instantaneous power and is suitable for the light sensation of negative films. A series of photographs which describe the moving processes of the injection spray process of a diesel engine clearly and definitely were taken by means of a common camera and the stroboscopic photographic apparatus.

For the photographing of the spray injection process a high pressure vessel and machine of double-jet single-time injection are projected and manufactured.

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TITLE: "Investigation of the Formation of Mixing in the Quiescent Direct Injection Diesel Engine by Water Model"

SOURCE: Dalian DALIAN GONGXUEYUAN XUEBAO [JOURNAL OF DALIAN INSTITUTE OF TECHNOLOGY] in Chinese No 2, 1981 pp 37-42

TEXT OF ENGLISH ABSTRACT: According to the principle of similarity, a water model is used for investigation of the formation of mixing in the quiescent direct injection diesel engine.

The optimized matched relations between the combustion chambers and the nozzle configurations are found by the model test, and the whole process is recorded by a common cinematograph. The matched condition and its resulting analysis of five combustion chambers and two kinds of nozzles are introduced with special emphasis.

This kind of model test technique has the advantages of simplicity and intuitiveness. Hence it is much more convenient for the study of the mixing mechanism in diesel engines.

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TITLE: "A Study on High Frequency Numeral Measurement of Thermal Field"

SOURCE: Dalian DALIAN GONGXUEYUAN XUEBAO [JOURNAL OF DALIAN INSTITUTE OF TECHNOLOGY] in Chinese No 2, 1981 pp 43-48

TEXT OF ENGLISH ABSTRACT: In this paper, a method including photocell-optical fiber and a digital computer system for multi-point measuring of a thermal field is suggested.

The conventional method for measuring the rapid solidification process with a thermal couple-electro-potential meter or a thermal couple-high speed oscillograph cannot meet the demand of multi-point, tiny-time difference (timing) and high frequency measurement.

The new method is based on simulating and practical experiments and it has been proved that the new system is likely to satisfy the above demands.

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TITLE: "The Brittle Cracks along the Welded Fusion Zone of 4Cr25Ni20 Steel and 1 $\frac{1}{2}$ Cr $\frac{1}{2}$ Mo Steel Tubes after Long Exposure at 500°C"

SOURCE: Dalian DALIAN GONGXUEYUAN XUEBAO [JOURNAL OF DALIAN INSTITUTE OF TECHNOLOGY] in Chinese No 2, 1981 pp 49-54

TEXT OF ENGLISH ABSTRACT: Tubes of the primary reformer furnace of an ammonia plant were examined through dye penetrate, macro and micrometallographic, microhardness and micro-probe tests.

The results of the examinations show that after 20,000 hours of operation at 500°C, the carbons of the 1 $\frac{1}{2}$ Cr $\frac{1}{2}$ Mo steel diffused from heat affected zone to the welded fusion boundary; the 1 $\frac{1}{2}$ Cr $\frac{1}{2}$ Mo steel side of the welded fusion boundary was decarburized and a thin shell-like brittle carbide was precipitated along the fusion boundary of the welding seam; the hardness of the welded fusion zone was increased. These are the reasons for the brittle cracks along the welded fusion zone. Cracks started from the root of the welding seam.

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TITLE: "The Structure of Aluminum-Silicon Eutectic Piston Alloys"

SOURCE: Dalian DALIAN GONGXUEYUAN XUEBAO [JOURNAL OF DALIAN INSTITUTE OF TECHNOLOGY] in Chinese No 2, 1981 pp 55-61

TEXT OF ENGLISH ABSTRACT: This investigation shows that, in order to assure better piston service, the alloys having granular or acicular structure treated by phosphorus (P) are available. The variations in morphology of eutectic in aluminum-silicon alloys, with and without phosphorus treatment, were examined. These differences in structure can be explained in terms of the concept of the existence of different types of clusters in the liquid state. The investigation also shows that in ZL108 alloys magnesium (Mg) coarsens the silicon crystals, but copper (Cu) and manganese (Mn) have adverse effects.

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TITLE: "Numerical Simulation of the Jolt Process of the Pneumatic Small Amplitude Jolt Molding Machine"

SOURCE: Dalian DALIAN GONGXUEYUAN XUEBAO [JOURNAL OF DALIAN INSTITUTE OF TECHNOLOGY] in Chinese No 2, 1981 pp 62-68

TEXT OF ENGLISH ABSTRACT: In this paper, a computation program based on a dynamic model on the small amplitude vibration mechanism of a jolt molding machine is proposed. The interaction among dynamic changing of gas, impact and vibration systems is comprehensively considered in this model.

In terms of an appointed step of time, this program can output calculating data. It follows that all the information of small amplitude jolt process is obtained during the course of the transitional process of impact motion from starting to holding out stabilization. The information is vibrating-iron coordinates,

[Continuation of DALIAN GONGXUEYUAN XUEBAO No 2, 1981 pp 62-68]

vibrating-iron velocity, gas-pressure, time through transitional process, times of impact motion, period of vibration, rating-energy of impact and indicating-work diagram, etc.

The calculated values check well with the results of tests. This program can be used to simulate both the normal impact motion and the non-normal impact motion.

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TITLE: "The Application of Bond Graph and State Space Analysis in the Research of Dynamic Characteristics of Fluid Power Systems"

SOURCE: Dalian DALIAN GONGXUEYUAN XUEBAO [JOURNAL OF DALIAN INSTITUTE OF TECHNOLOGY] in Chinese No 2, 1981 pp 69-78

TEXT OF ENGLISH ABSTRACT: Up to now, in the dynamic analysis of fluid power systems the transfer function analysis from the classical control theory was often used. This method has its limitations. Based on literature from China and abroad, in this paper the state space analysis from the modern control theory is applied to dynamic analysis of the fluid power systems of machine tools, and bond graphs are used to efficiently build the state equations of researched systems. This method may be used for nonlinear systems with multiple input and multiple output variables, and the initial values of variables may not be zero. The dynamic characteristics of several interested output variables may be obtained by use of the computer. Therefore, this method is particularly suitable for more complex fluid power systems. In this paper a typical system is analyzed in theory and is compared with the

[Continuation of DALIAN GONGXUEYUAN XUEBAO No 2, 1981 pp 69-78]

experimental results. This investigation indicates that this approach is feasible for the dynamic analysis of fluid power systems.

AUTHOR: ZHANG Yigong [1728 6318 1872]
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ORG: All of Dalian Institute of Technology

TITLE: "Design of the Calibration Equipment for the Three-dimensional Force Transducers"

SOURCE: Dalian DALIAN GONGXUEYUAN XUEBAO [JOURNAL OF DALIAN INSTITUTE OF TECHNOLOGY] in Chinese No 2, 1981 pp 79-83

TEXT OF ENGLISH ABSTRACT: This paper deals with the principle, structure and force analysis of the calibration equipment for the three-dimensional force transducers, as well as the means by which its accuracy and stiffness can be increased. The methods of regulation and use of this equipment are also introduced. The results obtained from the force analysis for selecting the location of tangential loading points can not only be used for determining the optimum location of these points, but also can be of reference value in the design of transducers and force measuring instruments.

AUTHOR: YU Yuxiu [0205 5124 0208]

ORG: Dalian Institute of Technology

TITLE: "Application of Ocean Wave Simulation"

SOURCE: Dalian DALIAN GONGXUEYUAN XUEBAO [JOURNAL OF DALIAN INSTITUTE OF TECHNOLOGY]
in Chinese No 2, 1981 pp 84-90

TEXT OF ENGLISH ABSTRACT: In this paper, the practical application of the two methods, wave superposition method and linear filter method, for simulating ocean wave processes are studied. Some questions which we must pay attention to in simulation and the basic characteristics of the wave obtained through simulation are also discussed. The results of simulation nearly conform to the realistic ocean wave and the simulation of the ocean wave would be an effective means for studying the ocean wave and its action on structures.

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TITLE: "A Method for Reductions of Initial Sets (I)"

SOURCE: Dalian DALIAN GONGXUEYUAN XUEBAO [JOURNAL OF DALIAN INSTITUTE OF TECHNOLOGY]
in Chinese No 2, 1981 pp 91-94, 12

TEXT OF ENGLISH ABSTRACT: In iterative computations for optimization algorithms, estimation of initial sets depends mainly on experimental guiding principles or making a guess at argument sets. In this paper a method for reductions of initial sets that is used to fix initial sets is presented in order to transform global optimization into local optimization in the sense of functional values, that is, an initial set is chosen according to functional values. It is possible to reduce blindness for fixing initial sets and improve computative reliability. We state simply the basic principle of the method in this paper. This paper is divided into four passages, with the principle of reductions presented in the second passage. In the third passage we give major steps of the algorithm for reductions of initial sets.

AUTHOR: YU Dazhen [0061 1129 4176]

ORG: Dalian Institute of Technology

TITLE: "The Model Theory of Dynamics"

SOURCE: Dalian DALIAN GONGXUEYUAN XUEBAO [JOURNAL OF DALIAN INSTITUTE OF TECHNOLOGY]
in Chinese No 2, 1981 pp 95-98

TEXT OF ENGLISH ABSTRACT: The model theory of dynamics is summarized in this paper. This theory provides the foundation in theory for modeling, the model experiment and in transferring the results from the model to the prototype, and may offer a reference for the researcher of experimental stress analysis.

AUTHOR: PAN Jinchang [3382 6930 1281]

ORG: Dalian Institute of Technology

TITLE: "The Use of the Mechanical Wave Maker of the Flap Type to Produce Irregular Waves"

SOURCE: Dalian DALIAN GONGXUEYUAN XUEBAO [JOURNAL OF DALIAN INSTITUTE OF TECHNOLOGY]
in Chinese No 2, 1981 pp 99-102

TEXT OF ENGLISH ABSTRACT: In this paper a discussion is given of the possibility of using the flap-type mechanical wave maker to produce irregular waves, changing the voltage of the DC power for a certain eccentricity e of the flying wheel. Some results are given here, and also a comparison is made with characteristics of the natural wave spectrum.

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CSO: 4009/254

Engineering Thermophysics

AUTHOR: YAN Jialu [0917 1367 7498]

ORG: Harbin Institute of Technology

TITLE: "Thermodynamic Principles and Formulas for Choosing Working Fluids and Parameters in Designing Power Plant of Low Temperature Heat"

SOURCE: Beijing GONGCHENG REWULI XUEBAO [JOURNAL OF ENGINEERING THERMOPHYSICS] in Chinese No 1, Feb 82 pp 1-7

TEXT OF ENGLISH ABSTRACT: In this paper, the author points out that there exist two different conditions of supplying low temperature heat. One is the invariance of mass rate of the hot fluid, and the other is the invariance of the amount of the supplying heat. From the thermoeconomic respect, these two conditions demand the working fluids differently or even contrarily in some thermophysical properties.

Then, from the thermodynamic theory and the characteristics of electric generation from low temperature heat, the author has derived four formulas for calculating the optimal temperatures of vaporization and condensation of working fluids and four other formulas for calculating the correcting coefficients.

Through a large number of calculations for various working fluids and various parameters, these formulas are proved to be reliable and accurate. These formulas will serve as a convenient means for the thermodynamic calculations in designing

[Continuation of GONGCHENG REWULI XUEBAO No 1, Feb 82 pp 1-7]

a power plant of low temperature heat, and a great deal of time spent on these calculations will be saved.

AUTHOR: ZHU Mingshan [2612 2494 0810]
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HUANG Zhiqian [7806 1807 3383]

ORG: ZHU and LU both of Qinghua University; HUANG of the Petroleum Exploration and Development Research Institute

TITLE: "Control of Turbine Inlet Temperature and Correction of Turbine Speed when Thermodynamic Performances of Single Shaft Constant Speed Gas Turbine Generator Set Is Tested on Site"

SOURCE: Beijing CONGCHENG REWULI XUEBAO [JOURNAL OF ENGINEERING THERMOPHYSICS] in Chinese No 1, Feb 82 pp 8-11

TEXT OF ENGLISH ABSTRACT: In this article, the authors have proposed a method to calculate the control curves of rated turbine inlet temperature while knowing only a few design parameters. The authors have also proposed a method to calculate the influence of turbine speed of the output of the generator set. It was verified by tests that the conclusions from this article have practical significance for conducting the thermodynamic performance tests of single shaft constant speed gas turbine generator sets properly.

AUTHOR: ZHANG Shiying [1728 0013 5391]
GAO Siting [7559 1835 1694]

ORG: Both of Nanjing Aeronautical Institute

TITLE: "Mathematical Simulation of Plate Distortion Simulator"

SOURCE: Beijing CONGCHENG REWULI XUEBAO [JOURNAL OF ENGINEERING THERMOPHYSICS] in Chinese No 1, Feb 82 pp 12-19

TEXT OF ENGLISH ABSTRACT: This is a record of our work since the previous article. New methods of simulation of the flow field behind the simulating plates, by which improved accuracy is obtained, are recommended. By simulating multiple and step-shaped radial plates and non-radial plates with quite good results, the extent of simulation is expanded. Through examples of simulation exercised, error in DC60 within 13 percent as compared with the experimental values can be achieved. Thus the foundation of computer-aided design of the simulating plates is laid further, and less cut and try [sic] is possible.

AUTHOR: LAI Shengkai [6351 5116 6963]
SUN Tongfan [1327 0681 5400]

ORG: Both of the Harbin Institute of Technology

TITLE: "Numerical Investigation of the Influence of Inner Shrouds on the Aerodynamic Performance of Stator Cascades in Axial Flow Compressors"

SOURCE: Beijing GONGCHENG REWULI XUEBAO [JOURNAL OF ENGINEERING THERMOPHYSICS] in Chinese No 1, Feb 82 pp 20-26

TEXT OF ENGLISH ABSTRACT: A study of the flow in compressor stator cascades with and without inner shrouds was carried out by means of numerical calculation. The study shows that the existence of the inner shroud which removes the effect of the moving hub has significant influence on the flow in the end region. Avoiding the use of the inner shroud can improve the flow. In certain cases this improves the surge characteristics of the compressor.

AUTHOR: SUN Tongfan [1327 0681 5400]
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ORG: Both of the Harbin Institute of Technology

TITLE: "Numerical Calculation of the Viscous Flow in a Divergent Channel with Rectangular Sections"

SOURCE: Beijing GONGCHENG REWULI XUEBAO [JOURNAL OF ENGINEERING THERMOPHYSICS] in Chinese No 1, Feb 82 pp 27-29

TEXT OF ENGLISH ABSTRACT: A numerical procedure was worked out to calculate the parabolized flow within a divergent channel. Unlike the existing methods, an overall iteration scheme was proposed to solve the three equations for the secondary flow. While the new procedure is simple and requires less computer time and storage space, it gives reasonable results.

AUTHOR: WU Wen [0702 2429]
CHEN Mingzheng [7115 6900 6927]

ORG: Both of the Institute of Engineering Thermophysics, Chinese Academy of Sciences

TITLE: "Some Results of Theoretical Analysis, Calculation and Experimental Research of Pressure Wave Supercharger"

SOURCE: Beijing GONGCHENG REWULI XUEBAO [JOURNAL OF ENGINEERING THERMOPHYSICS] in Chinese No 1, Feb 82 pp 30-38

TEXT OF ENGLISH ABSTRACT: This paper reports briefly our experimental results and theoretical calculations in the course of developing the pressure wave supercharger.

In the early stage of our work, we made pressure measurements on stationary end walls, dynamic pressure measurements of one point in the rotor channel, leakage testing and rotor surface temperature measurements. We completed our self-support experiment (i.e., without external pressure-air reservoir) on the C-2 machine in December, 1974. Now we have found a lot of designs of the port openings of the gas and air. For the first time we have initiated a water-cooled design to improve the performance. The preliminary experimental results of the new design were quite encouraging.

[Continuation of GONGCHENG REWULI XUEBAO No 1, Feb 82 pp 30-38]

We have done our theoretical work with the graphical method, numerical solution based on finite-difference equations and numerical calculations on the characteristic method. Here we mainly discuss the numerical solution based on finite-difference equations--one-step method and two-step method. The calculating results show clearly the front of the interface and the pressure wave as well as the velocity and mass flow distributions at all port openings. The calculating results and the experimental data are compared and discussed.

AUTHOR: HUANG Zhaoxiang [7806 0340 4382]
WANG Shiming [3769 0013 2494]

ORG: Both of the Institute of Engineering Thermophysics, Chinese Academy of Sciences

TITLE: "A Single Stage Supersonic Gas Ejector"

SOURCE: Beijing GONGCHENG REWULI XUEBAO [JOURNAL OF ENGINEERING THERMOPHYSICS] in Chinese No 1, Feb 82 pp 39-47

TEXT OF ENGLISH ABSTRACT: The optimum ejector performance of a single-stage supersonic gas ejector of the central induction type could be obtained by adjusting its two main geometric parameters, D_{ni} and L_{ni} . Better ejecting performance at higher vacuum conditions would be realized at $D_{ni} = 1.3 - 2.17$ and $L_{ni} = 3-5$ within the limits of our experiments using different nozzles. $n\sqrt{\theta}$ could be kept as a constant value as the temperatures of primary and secondary flows vary. The combined ejecting performance of two ejectors operated in parallel could be maintained at the same level as the individual ejector.

AUTHOR: LIU Diankui [0491 3013 7608]

ORG: Institute of Engineering Thermophysics, Chinese Academy of Sciences

TITLE: "Calculation of Cascade Flow with Mixed Boundary Conditions"

SOURCE: Beijing GONGCHENG REWULI XUEBAO [JOURNAL OF ENGINEERING THERMOPHYSICS] in Chinese No 1, Feb 82 pp 48-51

TEXT OF ENGLISH ABSTRACT: Making an S_1 stream surface equipped with splitter blades for use as an example, a cascade flow solution with mixed boundary conditions is proposed in this paper. A supposed physical model of the flow division in the cascade is given. It is successful in computer practice. The unification of theory and experiments is shown from the calculating results on a centrifugal compressor hub S_1 stream surface.

These ideas can be extended to include fan compressor S_2 surfaces and tandem blades.

AUTHOR: WANG Buxuan [3769 5943 1357]
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ORG: All of Qinghua University

TITLE: "Measuring Method and Error Analysis for Determining the Thermal Diffusivity of Low-conductivity Materials with a Conventional Twin-plate Device"

SOURCE: Beijing GONGCHENG REWULI XUEBAO [JOURNAL OF ENGINEERING THERMOPHYSICS] in Chinese No 1, Feb 82 pp 52-59

TEXT OF ENGLISH ABSTRACT: The thermal conductivity of the sample plates can be measured by conventional steady-state method with a twin-plate device. The electric current supplied to the heater is suddenly cut off, thus starting a transient process which has been analyzed theoretically for temperature response on the sample plate's hot surface with the consideration of the thermal capacity of the heater. However, as the transient process goes on, the assumption that cold surface temperature of the sample plate remains unchanged will not be satisfied. A more realistic model is shown, taking the coolant temperature as constant, and is solved numerically by the finite difference method. It is concluded from the computer-aided calculating results that the temperature response on the sample's hot surface approaches well that given by the equation as shown.

[Continuation of GONGCHENG REWULI XUEBAO No 1, Feb 82 pp 52-59]

The measuring techniques are well discussed based on an equation which is plotted as a figure, and the error of the measuring results is analyzed in detail while the error transfer function is given.

The test results made for foam concrete and optical glass K-9 are reported in the tables. The thermal diffusivities measured are compared well with those obtained by the plane heat source method with constant heat rate as reported in a previous article.

AUTHOR: GUO Zengyuan [6665 1073 0337]

ORG: Qinghua University

TITLE: "A New Calculation Method of the Temperature of the Arc Plasma in Non-LTE"

SOURCE: Beijing GONGCHENG REWULI XUEBAO [JOURNAL OF ENGINEERING THERMOPHYSICS]
in Chinese No 1, Feb 82 pp 60-66

TEXT OF ENGLISH ABSTRACT: It is usually difficult to obtain the temperature distribution in terms of the contactive measurement or the purely theoretical calculation. Non-LTE measurements of the line intensity and line width are needed for the evaluation of the temperature of arc plasma. In this paper we present a new calculation method with which the gas and electron temperature distribution and other parameters of arc plasma can be obtained by measuring the line intensity H_B only, and then by solving a system of equations. The experimental work can therefore be largely reduced. The energy equation of the gas and the integral of the current density have been used for examining the results. Good agreement demonstrates the reliability of this calculation method.

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ZHAO Jiaqi [6392 0857 3825]

ORG: All of the Institute of Engineering Thermophysics, Chinese Academy of Sciences

TITLE: "Experimental Investigations of Performance and Thermal Resistance of Gravity Assisted Heat Pipes"

SOURCE: Beijing GONGCHENG REWULI XUEBAO [JOURNAL OF ENGINEERING THERMOPHYSICS]
in Chinese No 1, Feb 82 pp 67-75

TEXT OF ENGLISH ABSTRACT: In this paper the experimental investigation of performance and thermal resistance has been carried out in gravity assisted aluminum-ammonia heat pipe and copper-water heat pipes. The influence of the inclination angle on limits to heat transport and film coefficients has been studied. The thermal resistance of the evaporator and condenser zone has been analyzed.

AUTHOR: LI Wanlin [2621 8001 2651]
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ORG: Both of the Chinese Academy of Space Technology

TITLE: "A Method for Calculating View Factors by a Computer Program"

SOURCE: Beijing GONGCHENG REWULI XUEBAO [JOURNAL OF ENGINEERING THERMOPHYSICS]
in Chinese No 1, Feb 82 pp 76-83

TEXT OF ENGLISH ABSTRACT: This paper presents a finite difference numerical method for calculating view factors of diffuse radiant heat transfer. The method is written as a standard computer program in FORTRAN.

The technology can calculate three-dimensional arbitrarily-oriented surface-to-surface view factors, including the effects of shading by interfering surfaces, and it is assumed that all surfaces are quadric surfaces.

The accuracy of view factors obtained by the method is about ± 2 percent, mainly depending on the chosen dependent variable (projected plan) and the size of grid points. In order to show the accuracy, four examples are presented in the paper.

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ORG: All of the Institute of Engineering Thermophysics, Chinese Academy of Sciences

TITLE: "Measurement and Analysis of the Transient Wall Temperature of the Rotary Combustion Engine"

SOURCE: Beijing GONGCHENG REWULI XUEBAO [JOURNAL OF ENGINEERING THERMOPHYSICS]
in Chinese No 1, Feb 82 pp 84-88

TEXT OF ENGLISH ABSTRACT: The transient wall temperature of an R-C engine was measured by surface thermocouples which were developed for this investigation. The probes had rapid response and reasonable reliability. The analysis of these results showed the existence of sweep flow in the R-C engine which had intensive effects on the heat transfer process. The flame propagation time was also measured by these thermocouples. The measured wall temperature and the flame propagation time data revealed the fact that the ignition and combustion in the R-C engine were not perfect.

AUTHOR: GAO Ge [7559 2960]
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ORG: Both of the Beijing Institute of Aeronautics and Astronautics

TITLE: "Theoretical and Experimental Study in Stability of the Barchan Dune Vortex Flame"

SOURCE: Beijing GONGCHENG REWULI XUEBAO [JOURNAL OF ENGINEERING THERMOPHYSICS] in Chinese No 1, Feb 82 pp 89-95

TEXT OF ENGLISH ABSTRACT: The three-dimensional Navier-Stokes equation describing the recirculating flow field behind the trailing edge of the Barchan Dune vortex generator was solved numerically by the Artificial Damping and Compressibility Method. The structure and stability of the Ox-horn shaped vortex scroll were analyzed. Due to the arching effect and the pumping effect of the diverging sources at the tips, the Barchan Dune vortex scrolls possess a tenacious anti-disturbance property. Experimental results revealed that, compared with a V-gutter at the same blockage ratio, the drag loss of the Barchan Dune vortex generator was reduced by 75-80 percent; the range of lean blow-out limits was extended to about 8-fold at the same inflow rate; and the ignition of combustible mixture was much easier. The experiments supported the diagnostic criterion for vortex stability proposed by Gao Ge in a previous paper.

AUTHOR: ZHOU Lixing [0719 0500 5887]
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ORG: Both of Qinghua University

TITLE: "Mathematical Modeling of Two-dimensional Pulverized Coal Flames by Integral Method"

SOURCE: Beijing GONGCHENG REWULI XUEBAO [JOURNAL OF ENGINEERING THERMOPHYSICS] in Chinese No 1, Feb 82 pp 96-102

TEXT OF ENGLISH ABSTRACT: The numerical modeling of a two-dimensional pulverized coal flame, stabilized by a high temperature gas jet (nitrogen plasma jet), is proposed by using the integral method. Based on a Lagrangian treatment of the particle phases, the concept of a dilute suspension and the devolatilization and heterogeneous reaction models suggested by Stickier, et al., the integral equations of gas and particle phases are deduced. After introducing approximate gas profiles and submodels of the particle processes have been established, a system of simultaneous ordinary differential equations, which can be easily solved by conventional numerical methods and computer techniques, is presented. It can be shown that with some modifications the proposed method can be used for mathematical modeling of different cases of pulverized coal combustion and gasification, including coal-fired MHD combustors.

AUTHOR: ZHANG Yafu [1728 0068 1133]
REN Aifeng [0117 1947 1496]
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TITLE: "An Analytical Study of the Ignition of the Combustible Gas Stream by Heated Plate"

SOURCE: Beijing GONGCHENG REWULI XUEBAO [JOURNAL OF ENGINEERING THERMOPHYSICS] in Chinese No 1, Feb 82 pp 103-107

TEXT OF ENGLISH ABSTRACT: Employing the series expansion method the development of the reaction zone near the heated plate was calculated. By the ignition model based on the consideration of the behavior of the reaction zone development, the ignition of the combustible gas stream by heated plate was discussed.

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